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Some Things We Do Not Know About Steel

By ALBERT SAUVEUR ✠

A talk before the Philadelphia Chapter on its Fifth Sauveur Night February 5, 1938

INSTEAD OF ATTEMPTING TO TALK OF things I may fancy that I know about steel, I prefer to consider some of the many things I do not know, believing that my ignorance is shared by others. Moreover, it covers so vast a field that I shall not be in danger of running short of material. Indeed, in the time allotted to me I shall be able to explore only a very small corner of it.

If it be asked what is to be gained by talking about things we should know but do not know, it may be answered that it should promote the cultivation of becoming modesty. Nor should our ignorance be a source of humiliation. Let me quote what a great scientist has written:

"I know no more of electric and magnetic force, or of the relation between either electricity and ponderable matter or of chemical affinity, than I knew and tried to teach to my students of natural philosophy fifty years ago in my first session as professor."

That great scientist was Lord KELVIN. The real scientist never hesitates to confess his ignorance and is not humiliated thereby.

Allotropy of Iron

Let us start with the allotropy of iron. How accurate and complete is our knowledge of that phenomenon which plays so important a part in the treatment and properties of steel?

In 1885 OSMOND announced his discovery of the occurrence of the upper critical points in iron, the A_3 and A_2 points, the lower A point in carbon toolsteel having been discovered and so named by TSCHERNOFF. OSMOND logically inferred that iron (in distinction to steel) existed under three allotropic forms, namely gamma iron above A_3, beta iron between A_3 and A_2, and alpha iron below A_2. These conclusions were universally accepted, and for a while, at least, peace prevailed in that corner of the arena.

It was not, however, to be of long duration, as disquieting rumblings began to be heard which proved to be the forerunners of a concentrated attack on the very existence of beta iron as a distinct allotropic form, and you all know that it was successful, as the majority of metallurgists now no longer believe in it.

I shall spare you a repetition of the arguments used on both sides, but I shall recall that after it had been found by X-ray diffraction analysis that alpha iron and beta iron had the same space lattice, namely body-centered cubic, it was concluded that alpha iron and beta iron could not possibly be allotropically different, and the controversy appeared to be closed.

More recently, however, it has been reported that there is what may be regarded as a transition lattice between the face-centered arrangement of gamma iron and the body-centered of alpha iron, namely a tetragonal space lattice.

It takes courage to suggest that this might be the space lattice of beta iron, thus re-establishing the right of the latter to be considered as an allotropic form of iron distinct from gamma and alpha iron. In doing so I know that I am incurring the wrath of the implacable enemies of the unfortunate beta iron. But if I am one of its few surviving defenders, I trust that you will not attribute it to stubbornness on my part, nor to sentimentality. It is due solely to my belief that the thermal point A_2 has not yet

been satisfactorily explained on other grounds in spite of many clever and laborious attempts.

Another thermal critical point was later to be detected in iron and in very low carbon steel, the A_4 point, at some 1400° C., and the picture so clearly fixed in our minds by this time was to undergo a serious retouching.

Iron, we are now told, does not solidify as face-centered gamma iron, but with "body-centered cubic lattice", called delta iron, transforming into a face-centered lattice (gamma iron) in passing through the A_4 point and reverting to the body-centered arrangement, now called alpha iron, in cooling through the A_3 point.

A fully satisfactory explanation of so extraordinary a behavior on the part of an element has not yet been offered.

Notwithstanding this difficulty, we felt strongly entrenched in our belief that the element iron could exist in at least two allotropic forms characterized by two different space lattices. Indeed, we considered the allotropy of iron as an imposing manifestation of that physical phenomenon. We did not suspect that a further trouble was in store for us. Let its nature be briefly stated:

It has been known for some time that the additions of certain elements (tungsten, chromium, silicon, for instance) to iron containing a small amount of carbon causes the A_4 transformation to take place at lower temperatures while it lifts the A_3 point. For a sufficient amount of the special element, meanwhile keeping the carbon percentage constant, the two points meet, resulting in the so-called "gamma loop". All alloys whose composition lay outside the loop — that is, having more than the required amount of alloy — solidify with a body-centered lattice and remain body-centered to room temperature, both the A_4 and A_3 points being absent. It is also observed that the less carbon present the smaller the percentage of the special element needed to cause the disappearance of the allotropic points. It is argued from this and from the observation that highly purified iron has a slightly elevated A_3 temperature, that with zero carbon, or rather in strictly chemically pure iron, no addition of any foreign substance would be necessary to cause the elimination of those points — in other words, that pure iron does not undergo *any* allotropic transformations. According to this argument, the allotropic transformation of commercial iron would be due to the presence of impurities.

Blessed be these impurities! They give us gamma iron, upon which we depend for the hardening of steel by quenching and for the other valuable properties imparted to that metal by heat treatment in general — and to conceive of civilization without the products of steel tools is too appalling a spectacle to be contemplated. Again I say, blessed be these impurities!

It is interesting to note that if these anti-allotropists are right, pure iron is left with but one thermal critical point, the A_2 point, the black sheep of the family.

Metastable Microconstituents

Let us now pass to carbon, the second constituent of iron-carbon alloys, an element of extraordinary significance, standing like Atlas carrying the universe on his shoulders. Should carbon withdraw his support, the entire organic world would collapse.

Obviously a great deal is known of the properties and characteristics of carbon, the element, but as metallurgists we are chiefly concerned with its behavior when associated with iron to produce steel and cast iron. Above its melting point steel appears to be a true liquid solution of carbon in iron, and it is of more than passing interest to know exactly what happens to carbon when this liquid solution solidifies and cools to room temperature at various cooling speeds.

Indeed, an exact answer to this query should give us the explanation of the hardening of steel and of all other heat treatments to which the metal may be subjected.

In seeking the information we crave, we are immediately confronted with the existence of that compound of iron and carbon, Fe_3C, the carbide of iron known as cementite, which appears to be of greater moment to us than elemental carbon itself, and which leads us to consider steel not as an alloy of iron and carbon, but as an alloy of iron and carbide.

Whatever the condition in the liquid metal, we know that on solidifying (if it does not contain over 1.7% carbon) this liquid solution is converted into what is known as a solid solution, to which the name of austenite has been given, and we are now concerned with the condition in which the carbon is present in this solid solution. Does it now exist as molecules of the carbide Fe_3C, or in atomic dispersion, or in ionic dispersion? The consensus seems to be

that the carbide molecules because of their large size could not find room in the space lattice of gamma iron, and that the carbon therefore must be present in the atomic state.

We should now consider what happens to this solid solution as it cools slowly to room temperature. For the sake of simplicity let us assume steel of eutectoid composition — that is, containing about 0.85% carbon. As this alloy cools slowly through its thermal critical point $A_{3,2,1}$ at some 700° C., the solid solution is converted into an aggregate of ferrite and cementite, which signifies that in cooling through that critical temperature the solvent iron has undergone an allotropic transformation, passing from face-centered gamma iron to body-centered alpha iron, and that each atom of carbon in coming out of solution has associated itself with three atoms of iron, resulting in the carbide Fe_3C, and this carbide has assembled itself in thin sheets throughout the alpha iron to form the familiar structure known as pearlite.

In 1934 the Philadelphia Chapter ⊛ started the graceful practice of naming one of its winter meetings "Sauveur Night" and to observe fitting ceremonies. Luckily Doctor Sauveur himself was asked to talk last year, and this was probably the last formal address he prepared before his sudden and untimely death. It was repeated substantially as printed before the Boston Chapter in October of 1938.

As first pointed out by Osmond, however, each austenite grain is not bodily converted into pearlite without passing through some transition stages, each with its own microstructure, and to these stages the names of martensite, troostite, and sorbite have been given. Some now claim, however, that those views so long considered orthodox must be abandoned.

A small group of metallurgists (or is it a large one?), taking exception to the earlier concept, claim that such transition constituents do not form when austenite is converted into pearlite. To me their claim savors of a sleight-of-hand performance, and one would like to be permitted to look up the sleeves of these prestidigitators.

Is it not evident that the cementite particles must at first be extremely small, in fact, submicroscopic, before acquiring microscopic dimensions? This stage, in my opinion, corresponds to martensite. This is followed by agglomeration of these minute particles, probably along certain metallographic planes of the mother austenite, and troostite comes into existence; and indeed, close examination under high power reveals the fact that the well-known lamellar structure of pearlite begins to be revealed. Further agglomeration yields sorbite, in which the lamellar structure is still more marked.

It is now claimed, however, that pearlite springs full-grown out of mother austenite as Minerva sprang full-armed out of the head of father Jupiter. Pearlite would be denied any babyhood, childhood, or adolescence.

Having ruled out of the metallurgical dictionary the terms troostite and sorbite, but not being able to do away with the microstructures they represent, these are to be described as pearlite of different degrees of fineness. This matter is worthy of some elaboration.

The constituent now universally known as pearlite was first described in print by Sorby in 1886 and named by him the "pearly constituent". Some years later Henry Marion Howe proposed to call it pearlite, and the suggestion was immediately accepted.

In 1910 a committee was organized by the International Association for the Testing of Materials to consider the nomenclature of the microscopic substances and structures of steel and cast iron. The committee included Henry Marion Howe, Floris Osmond, Henry C. H. Carpenter, William Campbell, Carl Benedicks, P. Wust, Alfred Stansfield, J. E. Stead, Leon Guillet, E. Heyn, Walter Rosenhain and your speaker, who served as secretary.

In the report presented in 1912 the committee defined pearlite in the following terms: "The iron-carbon eutectoid consisting of alternate masses of ferrite and cementite — a conglomerate of about six parts of ferrite and one of cementite."

This definition of pearlite represented the unanimous opinion of students of the microstructure of steel. I, for one, adopted it in common with other writers. Not until quite recently has it been challenged.

It is evident that pearlite has always been considered as the microscopical constituent formed during the slow cooling of austenite of eutectoid composition, and that pearlite therefore has a constant carbon content in the vicinity of 0.85% and that it consists therefore of 12.75% ferrite and 87.25% cementite. Not until austenite reaches the eutectoid composition can pearlite be formed.

In recent years, however, some have evidenced their intention to ignore these fundamental considerations and to describe as pearlite constituents varying greatly in carbon content — in fact, they propose to describe as pearlitic all aggregates of ferrite and cementite, possibly excepting martensite (although to be logical they should include it also).

To clarify, let us consider steel containing some 0.40% carbon in the form of a bar of moderate cross section cooled in air from a temperature of 900 or 1000° C. The resulting microstructure has always been described as sorbitic, following in this the suggestion of Howe. Those to whom I have referred would call it pearlite, although it contains but half the normal carbon content of the eutectoid.

In justification of their contention they point to the occurrence in this sorbitic constituent, when examined under high power, of small particles exhibiting a lamellar structure. Before we are unduly impressed by this piece of evidence, let us reflect that if these particles of pearlite within the sorbitic structure have the same carbon content as the steel itself, namely 0.40% carbon, then the ferrite lamellae should be some 15 times larger than the cementite lamellae.

If we believe that eutectoid composition must be reached before pearlite can form, the existence of pearlite particles within the sorbitic matrix is readily explained on the ground that locally eutectoid composition has been reached through rejection of ferrite into the surrounding matrix. It represents the normal and gradual transformation of sorbite into pearlite.

The views expressed by these writers imply so momentous a change in the nomenclature of the metallographic constituents of iron-carbon alloys that they should not be permitted to creep in without being exposed to the glaring light of intelligent criticism. They should be submitted to a committee on nomenclature composed of well qualified persons. Our failure to do so and our loose acceptance of these novel views would lead to confusion.

Aging of Steel

Passing now to the aging of steel, is it not true that we are still groping in semi-darkness in our attempt to explain the phenomenon? While undoubtedly some solid solutions increase in hardness after quenching or after cold work deformation, the mechanism of that phenomenon is still imperfectly understood. The aging of solid solutions is generally ascribed to a precipitation of the solute in particles of submicroscopic dimensions, maximum hardness corresponding to a certain size known as the critical size. Whether this precipitation causes lattice distortion which in turn results in increased hardness, or whether distortion precedes precipitation, are questions which are still debated. To explain some anomalies recourse had to be had to the wholly speculative conception of the formation of "knots", meaning by that the assembling of atoms of the solute in some fore-ordained position preceding its precipitation. An hypothesis so clearly conceived for the purpose of getting out of a difficulty is not likely to survive.

One cannot help being impressed, when reading technical and scientific papers, by the lightheartedness with which some authors

embark on the task of casting new hypotheses whenever they deem it necessary, or sometimes merely to satisfy their fancy, with little regard to logic and the results of past experience.

We should move cautiously in our acceptance of hypotheses the accuracy of which cannot be verified by experiment. We should remember that an hypothesis is justified and useful only when employed as an hypothesis, and not as a fact. There lies the danger. In the first instance, it may promote advance, in the latter, greatly retard it. There are many instances of the harm done by hypotheses wrongly accepted as facts, and the uprooting process is slow and laborious.

Hypothesis non fungo is a famous saying of NEWTON, and HUXLEY wrote in his "Physical Basis of Life": "The assertion which outstrips evidence is not only a blunder but a crime." We should keep our feet on the ground, which does not mean that we should look down and not up, but which does mean that we should resist being carried away by Pied Pipers, however enticing their appeal, and above all we should beware of our friends who think they know it all and reject their dogmatism as incompatible with the true scientific spirit.

Conclusion

In conclusion, I should like to make a plea for independent thinking. We should treat with respect the opinions expressed by those we hold in high esteem, but we should not accept their views as indisputable truth. We should critically and intelligently examine the evidence offered in a spirit of absolute impartiality, nor should we be too much impressed by the number of those with whom we disagree.

We must not take it for granted that the element iron has no allotropic transformation because an outstanding metallurgist has expressed that opinion, nor must you take the other view because ALBERT SAUVEUR happens to entertain it, nor must we accept without reservation the belief of some that martensite and troostite do not form when austenite transforms into pearlite, and for like reasons we must not assume without careful consideration that the hardness of quenched steel is due to the extremely small size of the alpha grains it contains because a man whom we all esteem highly has formulated that opinion. How many are still staunch supporters of the existence of an amorphous phase at the grain boundaries in metals, an hypothesis defended by no less a metallurgist than the late WALTER ROSENHAIN?

As I have expressed it elsewhere, "Scientific honesty demands that you play havoc with the pet theories of your best friends if they stand in your way and if it is necessary to support your views. Your best friends should not in the least resent it — let them reply in kind if they have the ammunition." We are all travelling towards the same destination, although we may disagree as to the best road to follow, and it is proper that we should place as many obstacles as we can in the path of those who, in our opinion, are following the wrong direction.

Let me quote to you what FARADAY himself has said on that subject:

> "The philosopher should be a man willing to listen to every suggestion, but determined to judge for himself. He should not be biased by appearances; have no favorite hypothesis, be of no school; and in doctrine have no master. He should not be a respecter of persons, but of things. Truth should be his primary object."

VOLTAIRE expressed the same thought when he wrote: "He who seeks truth should be of no country."

On the other hand, in scientific matters, there is no more unworthy person than the man who is actuated by prejudice, by liking or dislike, in his estimate and criticism of the work of others. Such men have no place among scientists and should be read out of their ranks.

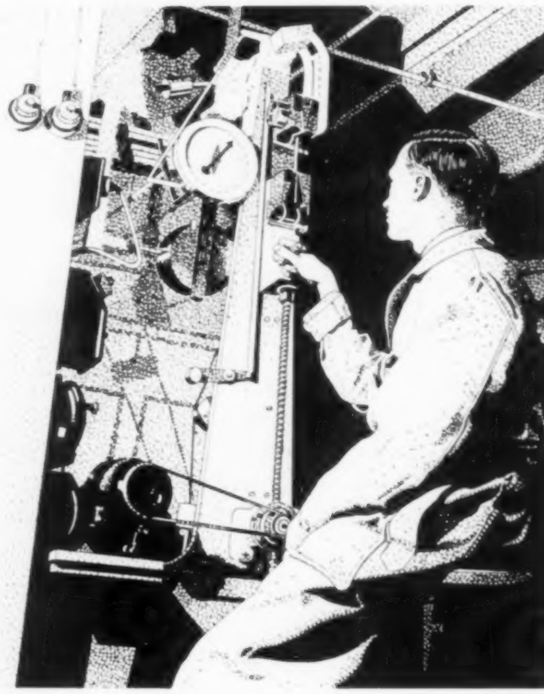
And now to conclude my conclusion and really to bring this talk to a close. I should like to make a plea for an uplifting attitude in our work, and indeed in all aspects of our activities. I cannot do better for that purpose than to quote from that excellent book, "Discovery, the Spirit and Service of Science" by Sir RICHARD GREGORY. It reads:

> "It is said that Thales of Miletus, who was the first of the Greeks to devote himself to the study of the stars, was on one occasion so intent upon observing the heavens that he fell into a well, whereupon a maid servant laughed and remarked, 'In his zeal for things in the sky he does not see what is at his feet!' "

Many men have been laughed at since for groping heavenward when their minds might have been occupied with affairs of the earth. There will always be the mind that strives to reach the skies, and the scoffer who regards all such aspirations as folly.

> "Two men stood looking through the bars:
> One saw the mud, the other saw the stars."

What is Wanted— Crosshead Speed, or Rate of Strain?



By PAUL D. FFIELD
Materials Engineer, Bethlehem Steel Co.
Shipbuilding Division, Quincy, Mass.

NOT SO LONG AGO WE INSTALLED A new hydraulic tensile testing machine in the physical laboratory at the Fore River Yards and were rather dismayed to be asked by the various inspectors, "What is the crosshead speed?" In fact, this caused us considerable trouble until we developed the attached table. This table was calculated particularly for our machine, which is of 60,000-lb. capacity, has three scales, and has a definite control on rate of loading in pounds per minute. (The note at the bottom of the table was included so as to get constant results from our automatic stress-strain recorder; in other words, it would be modified by others to suit their conditions.)

This seems to be a rather practical way out of a difficulty that has faced many testing engineers. We have given away a number of these tables, and they are generally useful, although most testing engineers have pertinent comments to make on the fog that envelops the subject of "speed of testing". For generality, the table could be made into a single column for metals with an elastic modulus of 10,000,000 psi. From such a basic table the crosshead speed in inches per minute could easily be calculated for other moduli, using a slide rule or mental arithmetic.

As to the necessity of some control of the rate of loading, I quote from A.S.T.M. E8—36, "Standard Methods of Tension Testing of Metallic Materials":

"4. The pulling speed has a marked influence on the tensile properties shown by materials tested, an increase in speed increasing the values found for yield point and tensile strength. The speed of head of the testing machine shall be such that the load can be accurately weighed.

"5. In determining yield strength, the crosshead speed for the 2-in. gage length shall not exceed 0.125 in. per min."

(Here let me digress long enough to say that not many engineers realize that this limiting requirement of 0.125 in. per min., when converted to stress for a standard 0.505-in. test bar actually means that the rate of loading must not exceed 325,000 psi. *per min.*!)

The phrase "determining yield strength" doubtless means in this specification "by the drop of the beam in a lever type of testing machine". However, there are various ideas as to *speed* expressed in various other specifications sponsored by the same society. For

instance, in A.S.T.M. A94—36, "Standard Specifications for Structural Silicon Steel" we read as follows:

"7. *(b)* The yield point shall be determined by the drop of the beam or halt in the gage of the testing machine at a crosshead speed not to exceed ½ in. per min. The testing machine shall not be stopped to obtain the drop of the beam or halt in the gage."

Other specifications may be quoted, all illustrating a lack of unanimity as to the correct maximum testing speed. Obviously it may be four times as high for an 8-in. gage length (plate specimen) as for a 2-in. gage length (½-in. round specimen), and still strain (stretch) the specimen at a reasonable rate, which presumably is what is desired. To be on the safe side we at the Fore River Yards stay well within the A.S.T.M. limits, as noted in the footnote of the table. Furthermore, it is doubtful if any autographic stress-strain recorder could operate with consistent accuracy when the rate of strain approaches 0.050 in. per min.

It should be noted that in this table the crosshead speed is supposed to be the same as the stretch in the 2¼-in. parallel section in the standard 0.505-in. round tensile specimen. At Fore River we have standardized on an all-purpose type of test bar with shoulder, and our socket-grips are sufficiently rigid so that this assumption is, we think, sufficiently accurate. In the step-down type of test bar with threaded ends the total extension of the specimen between threads is considerably larger. Thus, such a 0.505-in. steel test piece would stretch 0.000164 in. between threaded grips under a load of 300 lb. rather than the 0.000113 in. shown in the table for the extension of the parallel section of the same bar under the same conditions. Furthermore, it is not correct to assume that the crosshead speed is calculable even in this way if complicated yokes with ball and sockets or if tierods of considerable length are used. Likewise, no notice is taken of elastic movements in the crossheads and operating screws. Conditions are even worse if wedge grips with serrated jaws are used on specimens with smooth ends; much motion is used up by the teeth sinking into the ends of the test piece.

Basically, the engineer is really interested in the rate of strain within the test bar, and not in the speed of the crosshead of the testing machine. Our hydraulic tensile testing machine at Fore River is equipped with a device to control the rate of loading or stressing of the specimen. The rate of loading of course is directly proportional to the strain in the test bar within the elastic range of the material tested. It is unfortunate then that with definite control on the strain rate of the test bar we had to prepare a table to convert this strain rate to the crosshead speed of the machine in order to comply with a specification.

If the engineering societies and specification bodies would standardize on either a fixed rate of strain, or a fixed rate of stress (either of which could be calculated from the other, and either of which could be easily controlled mechanically) then the crosshead speed of a mechanical machine could very easily be determined with the aid of a watch should anybody wish to measure it.

It should however be clearly understood in any such specification or operation that the crosshead speed itself may have no bearing on the rate of strain of the test bar.

Crosshead Speed up to Elastic Limit

Calculated from the loading rate and elastic modulus for 0.505-in. standard test bar, 2-in. gage length

Dial Speed Lb. per Min.	Crosshead Speed in In. per Min.		
	Steel E = 30,000,000	Cast Copper Alloys E = 14,000,000	Cast Aluminum Alloys E = 10,000,000
300	.000113	.000241	.000337
500	.000188	.000400	.000563
1000	.000375	.000800	.00112
2000	.000752	.00161	.00225
4000	.001502	.00322	.00450
6000	.00225	.00483	.00675
750	.000282	.000603	.000844
1250	.000470	.00101	.00141
2500	.000940	.00201	.00281
5000	.00188	.00400	.00563
10000	.00375	.00800	.0112
15000	.00564	.01205	.0169
3000	.00113	.00241	.00337
5000	.00188	.00400	.00563
10000	.00375	.00800	.0112
20000	.00752	.0161	.0225
40000	.0151	.0322	.0450
60000	.0225	.0483	.0675

Maximum crosshead speed allowed in general specifications for inspection of metals: 0.050 in. per min.

When determining elastic limit by extensometer in general load specimens at 3000 lb. per min. up to yield point.

Polish Required for Examination in Polarized Light

By HAROLD L. WALKER
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Urbana

AN UNUSUAL AMOUNT OF INTEREST exists at present in the examination of the microstructure of metals under polarized light, because some very definite advantages accrue from its correct use. In many of the articles appearing in the current literature on this use of polarized light for the metallographic examination of anisotropic materials (crystals of metals having different properties in different directions referred to the crystallographic axes) it has been suggested that the polishing operation should be carefully executed in order to avoid the production of abnormal surface conditions which might lead to false conclusions. These surface anomalies supposedly arise from the flow of the surface during polishing, and take the form of a Beilby layer or amorphous film. Since amorphous substances have isotropic properties to polarized light, these amorphous or non-crystalline films are believed to prevent the proper examination of the crystal surface.

A study of polished surfaces seemed advisable to determine any effects of the flowed surface on polarized light. For this purpose the following materials, all of which show anisotropism, were studied: Tellurium, antimony, bismuth, magnesium, zinc, tin, cadmium, and arsenic.

The procedure for polishing was through 0000-carborundum paper to a rotating felt lap containing 600-grain alundum, to a lap with levigated alumina, and then to a lap saturafed with distilled water containing no abrasive. Beginning with the 600-grain alundum lap, microscopic examination followed each step of the polishing operation. The method paralleled and exceeded any ordinary polishing procedure both in length of time and in pressure exerted between specimen and polishing wheel. The time of polishing in each step was varied until a time had been reached of 2 hr. on the levigated alumina lap and of 3½ hr. on the water-saturated lap. The pressure exerted on the specimens was varied, by dead weight loading, for each of the operations until a maximum pressure of 500 g. per sq.cm. of surface for 2 hr. of polishing had been reached. A dry lap without abrasive was also tried, but it scratched the surface rather than polished it.

In this work, evidence for the extinguishing of anisotropic properties due to the formation of a film by polishing was not found in any of the examinations with polarized light.

Generally speaking, the anisotropic properties were stronger the longer the polishing operation and the better the polish. A poorly polished surface containing even very small scratches causes so much scattering of the incident light that the effect with crossed nicols is greatly diminished. It is to be noted that this experiment does not give evidence for or against the presence of an amorphous film, but it does seem to show that (Cont. on page 628)

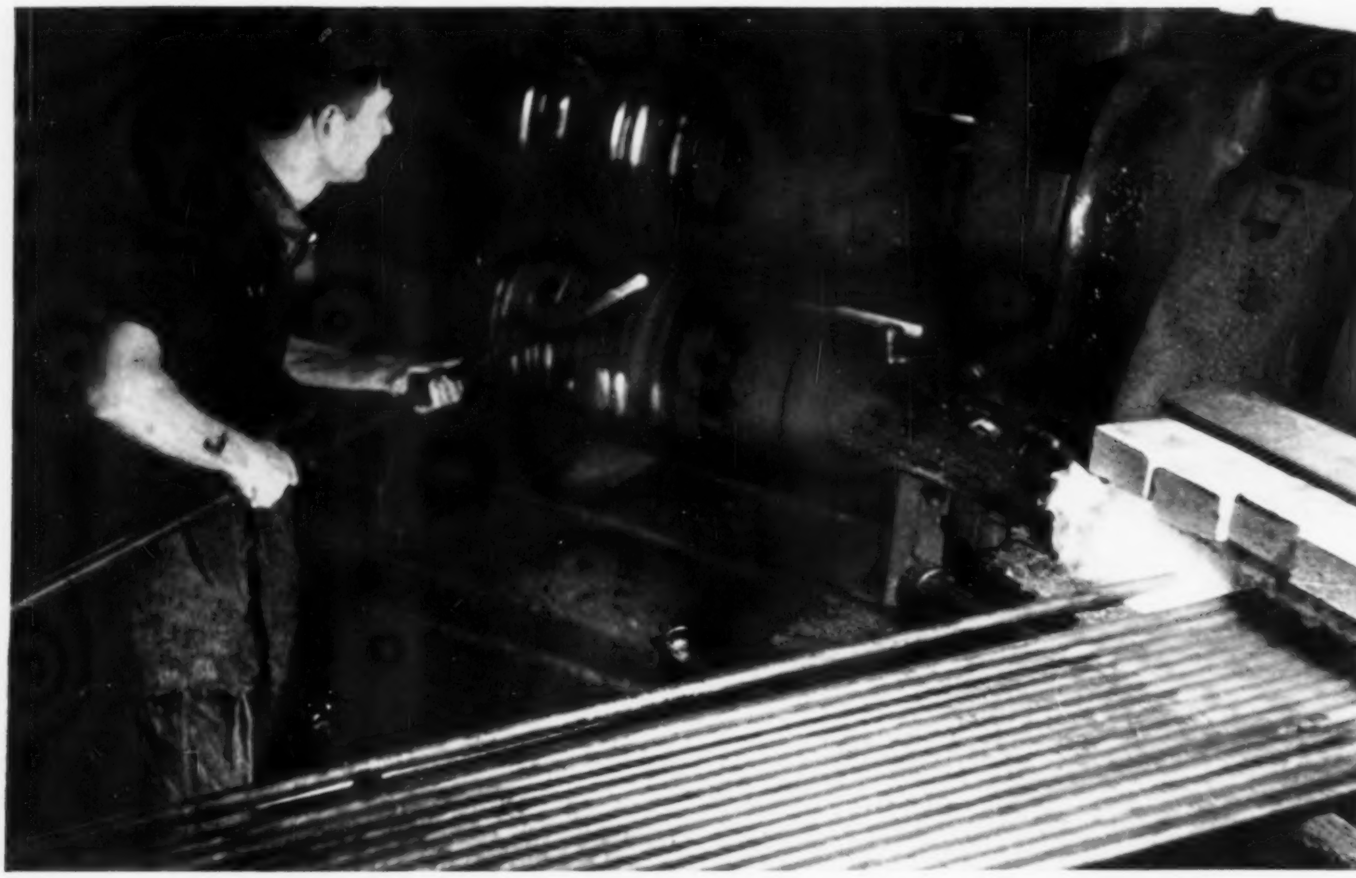
Normal Incident Light Reflected From Polished Metals

Metal	Wave Length	Reflection	Observer
Tellurium	590 $\mu\mu$	34%	Van Dyke
Antimony	589	53	
Bismuth	600	55	
Magnesium	600	73	
Zinc	589	74	Meier
Tin	589	82	Drude
Cadmium	700	98	Coblentz

Steel Golf Shafts

Pictures by VAN FISHER
Captions by GEORGE W. YEARLEY
Chief Metallurgist
American Fork & Hoe Co.
Geneva, Ohio

Replace Wooden



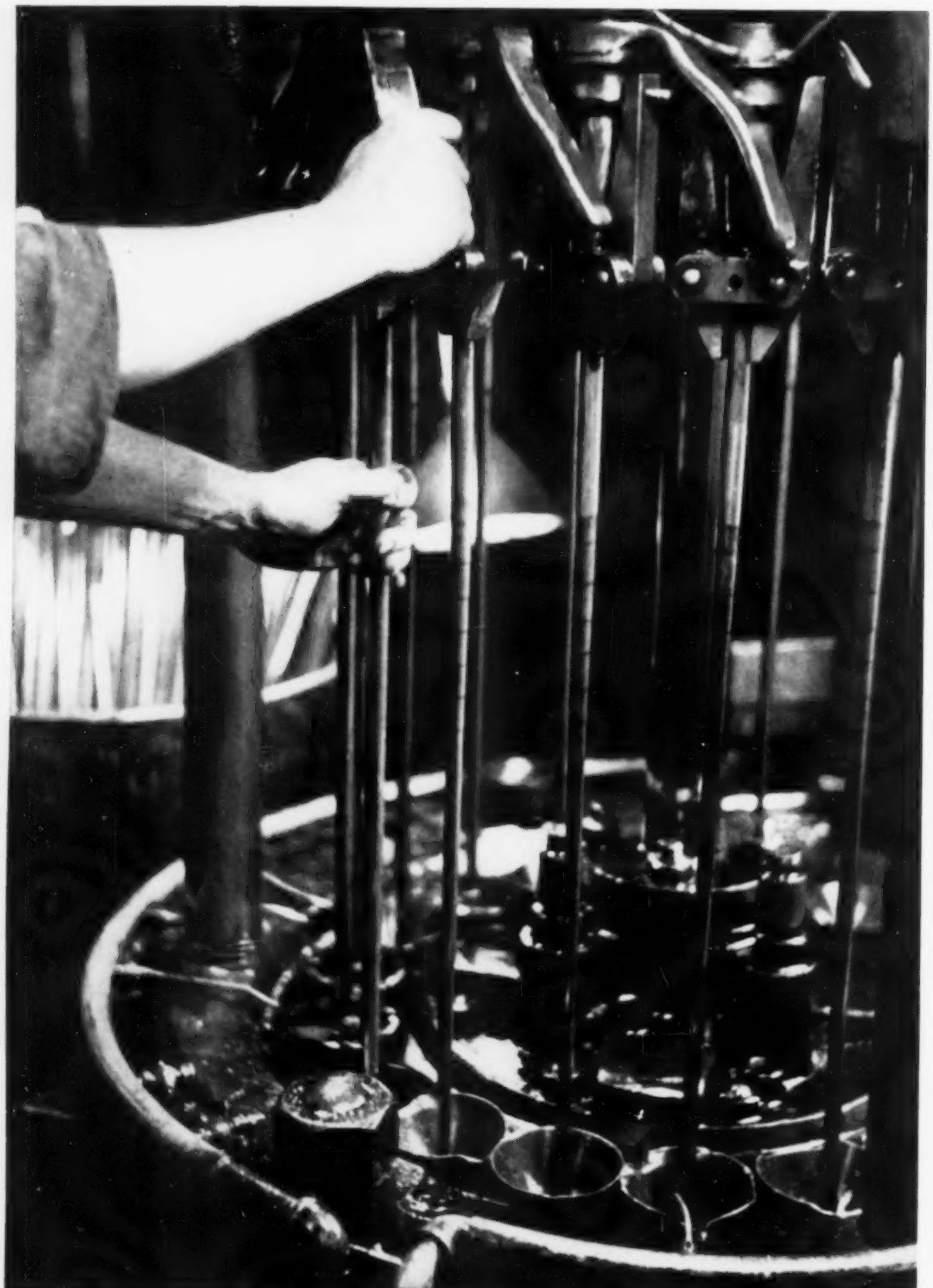
1 The production of high quality steel golf shafts is roughly divided into three major steps: First is the production of mirror surfaced alloy steel tubing of extremely close tolerances. Second is its tapering, heat treating and testing. Third is the application of rust resistant and decorative finishes for eye appeal.

2 *(above)* Hot pointing on a forging roll gives a uniform point with a minimum of waste in the thick-walled, seamless tubing received from the steel mill

3 Tubing must be annealed after each of the 12 reductions on the draw bench. View at right shows a workman loading tubing on a roller hearth furnace with controlled atmosphere to avoid any surface changes.

4 As surface finish is very important on such thin-walled tubing, pickling, cleaning and lubricating must be carefully watched in all stages of the cold drawing operations.

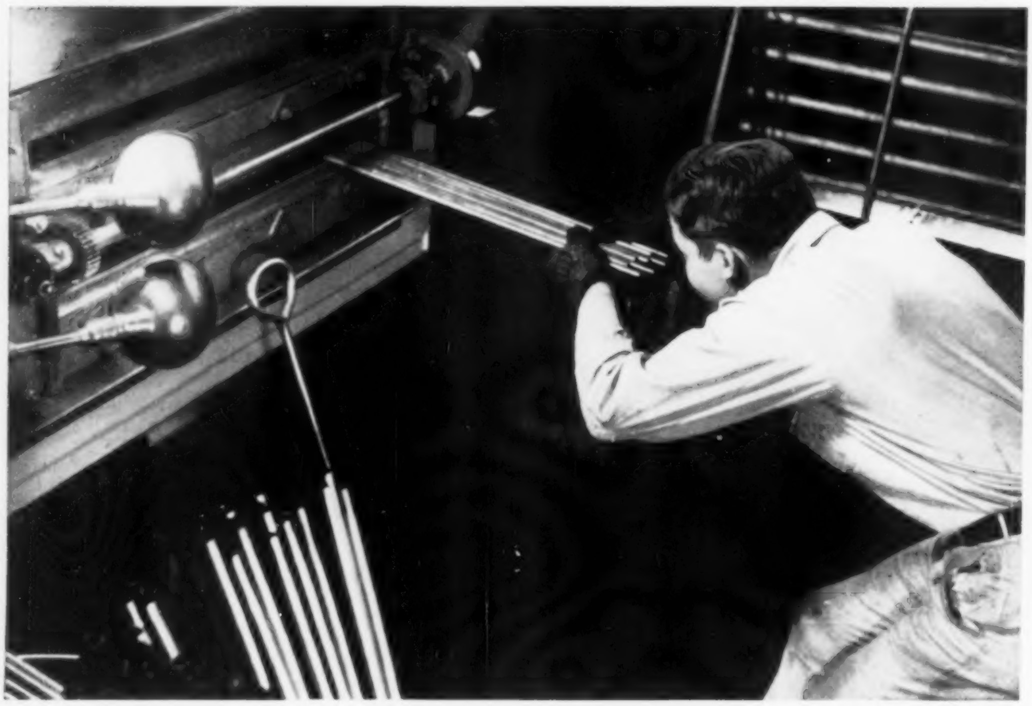
5 One of the tube drawing benches. Finished tubing for golf shafts has a wall thickness from 0.013 to 0.016 in. Other draw benches produce tubing with a constant outside diameter but taper the wall thickness so that finished shafts have about twice the wall thickness at the tip, where maximum strain occurs, as at the butt. Carboloy dies and mandrels insure fine finish and close tolerances on such tubing.



6 The workman is placing a cylindrical tube in the clamp under the head of a hydraulic ram. "Step tapering", done in this patented machine, consists in forcing the tube, station by station, through dies of steadily decreasing diameter, set at appropriate levels. This means of tapering readily adapts itself to changes in design and enables the flexibility to be adjusted to the needs of all types of players.

8 Poised above a vertical shaft furnace, a rack-load of shafts is ready for a journey through four heat treating operations. The flame is a bleeder stream from the carefully prepared atmosphere in the furnace, a bone-dry and oxygen-free mixture of hydrogen, nitrogen and carbon monoxide, adjusted to prevent any trace of scale or loss of carbon at the inner or outer surface of the thin-walled tube.

7 Tapering the tip end of the shaft, in a swaging machine, to fit the hole in the club head.

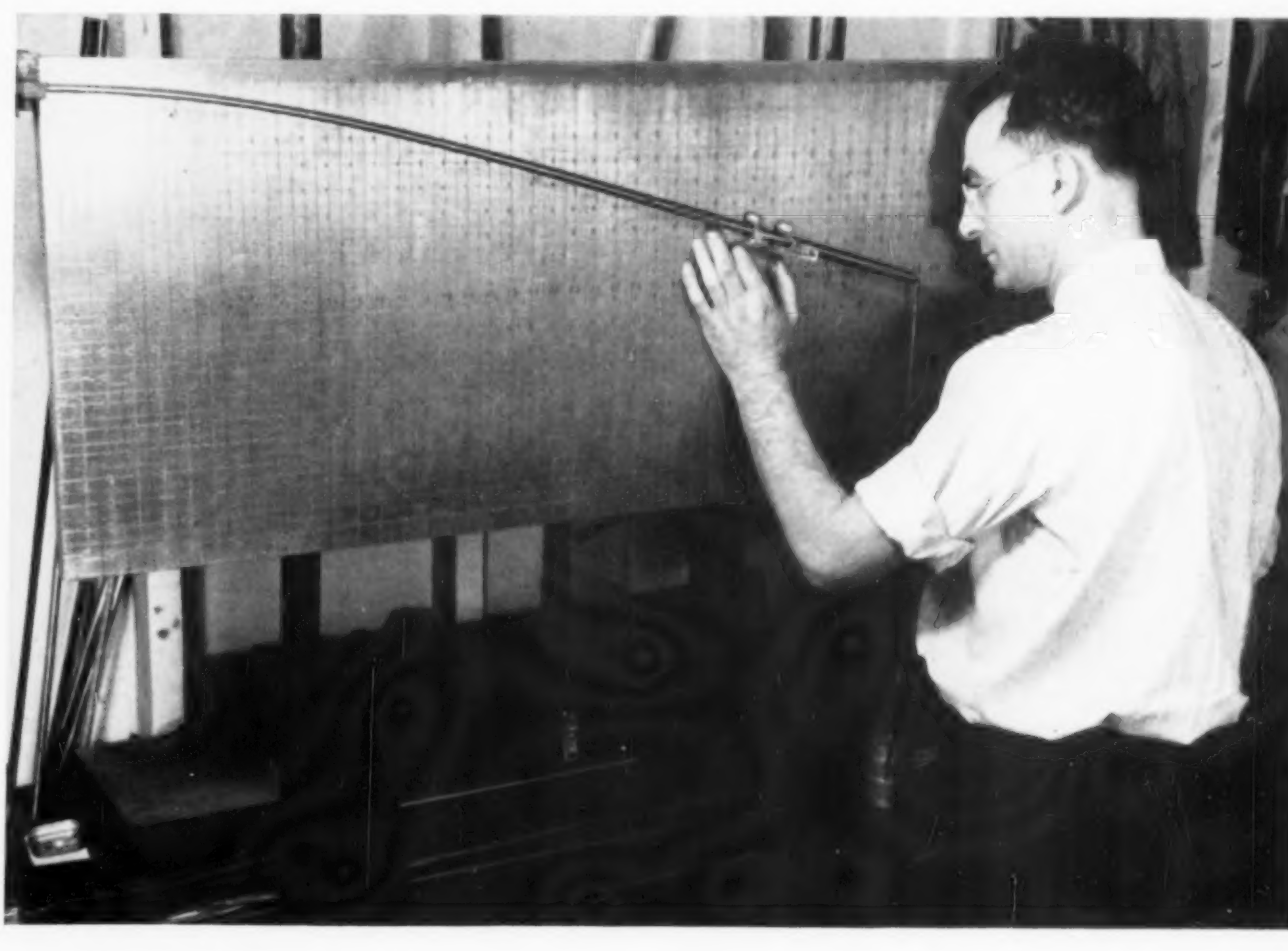


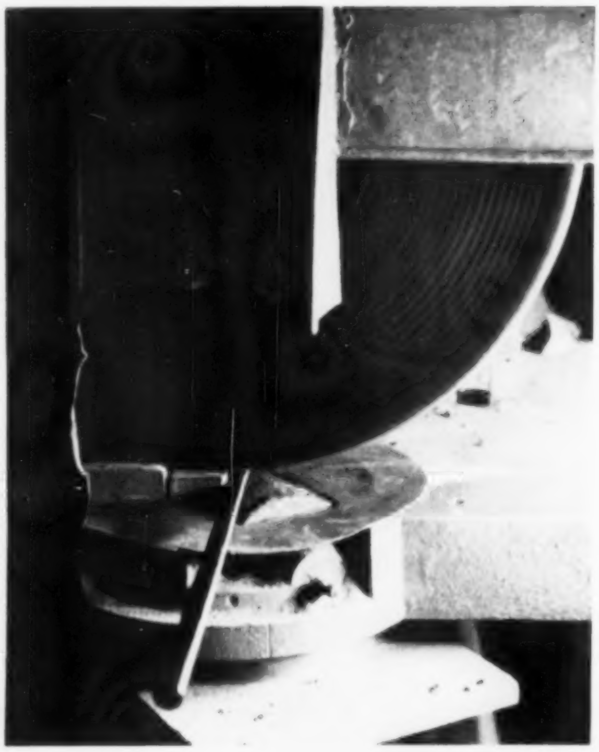
9 Loading hardened shafts into a die tempering and straightening furnace. Here the shafts are held between formed dies to overcome warping during the reheating operation.

10 *(below)* No mechanical substitute has been found for the trained eye and delicate touch of the hand straightener. Years of experience are necessary to train these experts to produce shafts straight as a gun barrel. This is one of six 100% tests to insure perfection in "Truetemper" golf shafts.

11 Testing *all* finished shafts for flaws with high pressure steam. Previous to this last test, each shaft is required to pass a series of three other tests — for flexibility, for stiffness and for "ring".

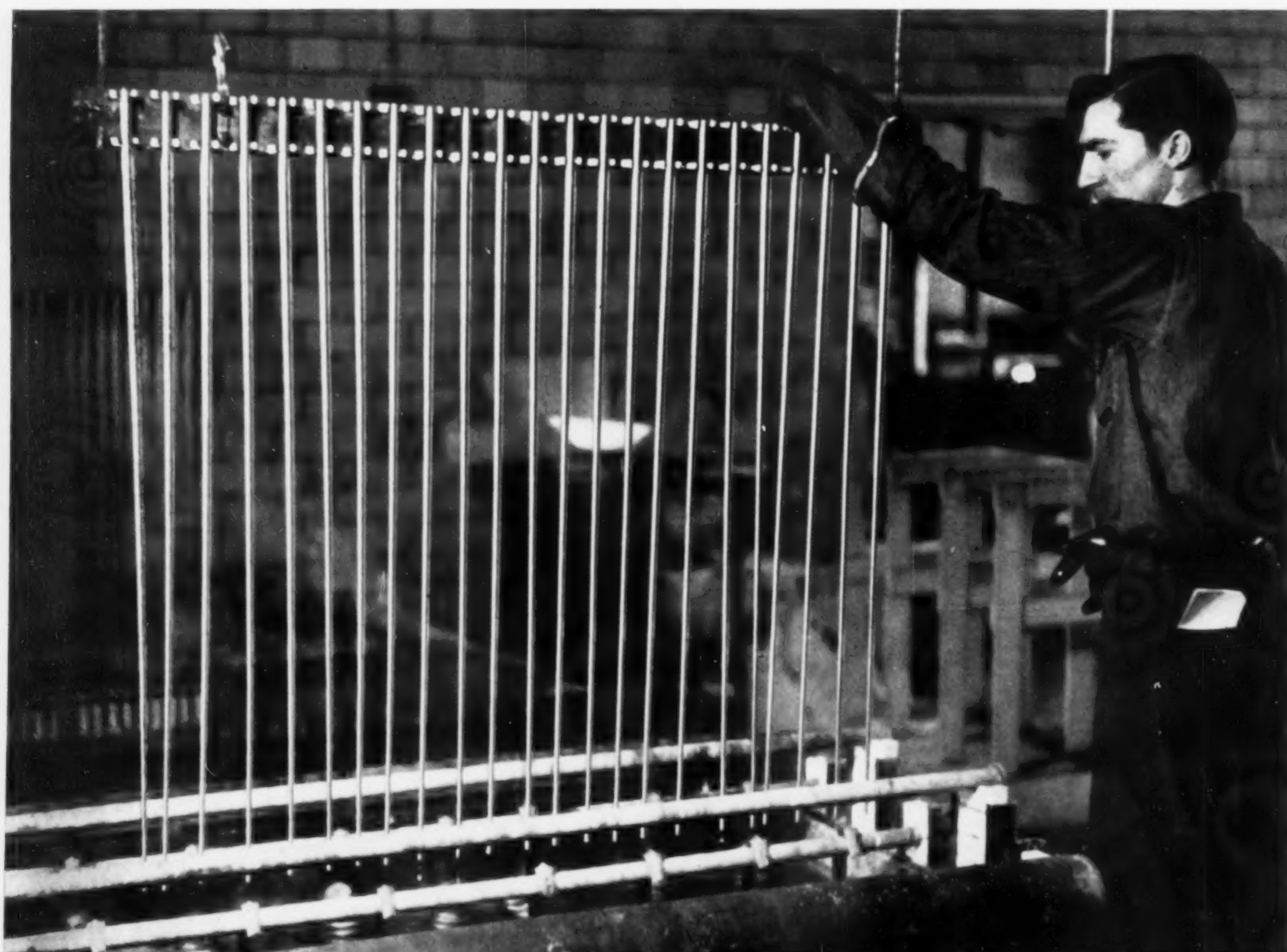
12 Design testing. This graduated test board enables the flexibility of a shaft to be determined under various loads and at any point on the shaft — something practically impossible to calculate accurately in a step-tapered tube such as this.





13 All shafts with metallic finish are brightly polished on buffing wheels set at a slight angle, as shown at left.

14 Chromium plate is a very popular finish, among the dozen that may be specified. In this model plating department successive deposits of copper, nickel and chromium are applied to the polished and cleaned steel.



15 Hydraulic lacquer dipping. If lacquered, golf shafts are given seven coats to beautify and protect them.

16 Each finished shaft is weighed, and if over or under weight by one-tenth ounce it is discarded. Finally it receives a thorough visual inspection. These shafts are now ready for shipment to the club manufacturers who will add heads and handles so that millions of golfers may alternately curse and kiss them.

Problems in Openhearth Steel Melting

By KARL W. GRANT
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A VERY FREE REPORT OF THE "OPENhearth Conference" held in Cleveland late in April by the American Institute of Mining and Metallurgical Engineers should violate the program arrangement and start at the beginning — namely the joint session of men interested in raw materials, blast furnace smelting and openhearth refining. This is logical because careful refining practice is needed to meet present-day requirements as to chemistry, cleanliness, grain size, hardenability and machinability of steel, and uniformity of iron and other raw materials is essential to avoid time-consuming and expensive correctives in the openhearth process.

The analysis of the scrap charged into the openhearth is usually constant within fairly narrow limits. Its physical condition can be seen and its probable effect allowed for when charged. A different set of conditions applies to the hot metal or pig iron. Its silicon may range from 0.60 to 1.50%, sulphur 0.020% and up, phosphorus 0.25 to 0.40%, and manganese from 1.50 to 2.00%. Effect of these variables on the way the heat melts, the slag condition and volume, and the time of heat is hard to appraise and difficult to control.

Silicon content in the iron was considered of the greatest importance by the openhearth commentators. If held reasonably constant at about 1%, no trouble is traceable to it. If it falls below, say in the range of 0.70 to 1.00%, it does cause variations in melting. If enough lime is charged for high silicon metal and low silicon metal is actually charged, the heat will not melt in a normal manner, and some corrective will have to be applied. The reverse of this condition, namely, insufficient lime to take care of an unexpected increase in silicon, will likely develop bank or bottom trouble. There were a number of acceptable ranges set for silicon content of hot metal, such as 0.90 to 1.20%, 0.70 to 1.00%, 1.10 to 1.50% — but the iron should always be within the expected range.

One openhearth operator even went further and said he depended on a better and more uniform grade of hot metal, with reasonably close limits as to chemistry, especially silicon, to take care of the changes in scrap from light and easily oxidizable during melt-down, to heavier and less oxidizable. This operator further believes the silicon range can be varied in accordance with the way the openhearth furnace works. Due to construction, regulation, fuel, and similar circumstances, some furnaces will oxidize much faster than others and as a consequence, it would require a higher silicon metal, whereas one which oxidizes slowly would require a low silicon iron.

Figures were presented showing what silicon variation can mean in the way of changing the slag volume on an openhearth heat. Assuming a 340,000-lb. charge, 45% of hot metal analyzing silicon 0.95%, limestone 9% of the total, and a 2.75 $CaO:SiO_2$ ratio desired, the slag would amount to 38,000 lb. With silicon at 1.25%, the weight would go up to 42,000 lb., and with 0.65% silicon down to 33,000 lb.

Another speaker showed how silicon affected temperature. Its oxidation by ferrous oxide raises the temperature of scrap-and-iron charges by 10.4° F. and oxidation by oxygen 29.2° F. for every 0.1% silicon. In high metal charges, oxidation by ferrous oxide raises the temperature 16.0° F. for each 0.1% silicon; oxidation by means of oxygen would mean 48.2° F. From a study of many heats covering a year's production, this steel maker concludes that low silicon (0.90% and under), with sulphur at 0.040% and over, causes *(a)* dirtier steel, *(b)* more heats of inferior quality, *(c)* slightly poorer macro-etches, and *(d)* higher final sulphur in the steel.

Sulphur was deemed by some to be the

most troublesome element; its elimination in the openhearth is an expensive operation. Its effect on the quality of the steel — particularly in applications requiring deep drawing and some types of heat treatment — is very pronounced. It was generally agreed that the blast furnace was the better place to get rid of it.

Phosphorus limits in the metal were, in most cases, set at around 0.30%, though some operators specializing on rimming steel had no objection to amounts as high as 0.40%.

Limits for manganese ran from 1.50 to 2.00%. Where the big tonnage is rimming steel, operators desired the lower side of the range; shops producing forging grades favored the higher.

The matter of temperature was frequently brought up in the discussion. High casting temperature was considered essential; one operator considered 2700° F. as the minimum. Temperature at charging into the openhearth furnace was also said to be 2450° F. minimum. Data were presented showing that, as the casting temperature fell below 2700° F., the quality of the steel fell off, and the percentage of poor heats increased, being 31% at 2615° F.

In reply to what the openhearth requires from the blast furnace, one blast furnace man thought the requirements sometimes involved metallurgical impossibilities. Thus, the combination of silicon around 1% with low sulphur sets up opposing conditions. High temperature is one of the important factors in producing low sulphur iron, and high temperature is also the thing that produces high silicon iron. To keep the two in balance, the blast furnace must juggle a number of other factors such as uniformity of the materials making up the furnace burden, slag composition, slag viscosity, blowing rate, blast temperature, and blast humidity, the last item being a matter over which there is little or no control.

The trend toward lower sulphur in the metal means a higher percentage of limestone on the blast furnace burden. One furnace man pointed out that a change in sulphur specification from 0.030% to 0.020% would increase the cost of hot metal by 20¢ per ton. If sulphur gets up to around 0.070%, the metal would have to be remelted at a cost of about $1 per ton.

Another blast furnace operator thought that, since the openhearth departments were the best customers, they should get as close to what they wanted as possible, and had a right to expect 80% of the metal to be within the specification. If low silicon iron was demanded, 0.50 to 0.70%, there would be a lot of trouble in the blast furnace department. With 0.80 to 1.20% silicon and 0.025% sulphur specified, the production of iron was much simpler. Holding manganese within a ten-point range was not difficult — in fact, specifications for merchant iron frequently require these limits. The speaker thought that the item of cost was stressed too much, because decisions as to cost were a function of the management, to be decided upon after all the factors involved had been presented by superintendents of blast furnace and openhearth departments.

In closing this joint session, L. F. Reinartz, the General Chairman, expressed the belief that the unanimity of opinion on the part of the openhearth men had put their desires more clearly than ever before. It had been clearly set forth *(a)* that the openhearth must have metal of greater uniformity, *(b)* that 80% good iron, 20% off-specification iron was not good enough, *(c)* that this could be bettered if the blast furnace operator be allowed to spend the money; and *(d)* that a joint recommendation to the management would clearly show that 20¢ extra cost of hot metal would be a very small item in the final cost of the finished product.

Openhearth Refractories

Use of "plastic chrome" as a bottom material and the results obtained were reported from several sources. A review of the developments in the construction of furnace bottoms, from solid concrete covered with 12 to 27 in. of magnesite, to the pan bottom of the modern openhearth furnace, shows that chrome brick and compounds have played an important role.

The first chrome bottom was laid in the form of an inverted arch. The materials used were 3 in. of insulation on the pan, 12½ in. of firebrick laid tight enough to hold water, 9 in. of chrome brick, 9 in. of chrome-magnesite brick, and 3 in. of magnesite mixed with 14% of roll scale and ground to 20 mesh.

Cost was about $1500 less than the conventional furnace bottom. The savings were made by using less magnesite and less fuel when "burning in".

Production figures for the first campaign show 267 heats at 135.3 tons average (55% hot metal, 45% scrap charge, and 8% limestone), 13.33 tons per hr. tap-to-tap, 21.67 tons per 1000 sq.ft. of hearth area, 4,140,000 B.t.u. per ton.

On rebuilding, there was found no disintegration of the top course, but some erosion at the slag line.

Performance and details were also reported from a midwestern plant, where a number of plastic chrome bottoms have been put in. Regarding the possible results should the metal go through the magnesite, one opinion was that the plastic chrome would hold. Another thought that it was better, in such event, not to depend on any plastic bottom to hold the heat, but to get it out of the furnace immediately. The suggestion that mixtures of alumina might be used as a bottom material was briefly discussed, but it was pointed out that combinations of alumina and lime form compounds with very low melting points and, consequently, its use was likely to be dangerous.

Various types of magnesite — Thomasite, Austrian, Washington, Canadian, Russian, and Sea Water — were discussed. All types had been tried, and aside from the idea that purity was always desirable there was, in general, little difference in the results obtained. No opinions were advanced as to the effect of grain size of the magnesite on its performance in furnace bottoms. Washing, charging low carbon heats, and scraping the bottom were some of the practical suggestions as to how to keep bottoms clean. Materials to be used for repairing bottoms depend on the extent of the job; the use of plastic chrome, double burned dolomite and magnesite were mentioned.

As to the probable life of a furnace bottom, one was reported as being put in some 21 years ago, but had probably been renewed down to the brick work during that period.

The matter of keeping bottoms in shape during periods of curtailed operation was discussed. One speaker said he had put into operation furnaces idle for 18 months with no abnormal trouble. The bottoms and banks were made up with burned dolomite just before being shut down. This dressing did slake and had to be removed but it protected the bulk of the refractory by limiting the extent of the slaking.

Use of basic brick and other special materials in openhearth furnaces other than bottoms was mentioned by one who had tried chrome-magnesite composition in front walls. Comparing an average of 110 heats per front wall built with silica brick, with 141 heats on one run and 123 heats on another run when the front wall was built of basic brick, he concluded that the increased number of heats would not justify the increased cost. Basic materials for furnace roofs, particularly the application made by European steel makers of "Radex" brick, were discussed. It has been reported that roofs made of these brick will stand an increase in roof temperature of 150° C. (300° F.) beyond what is safe for silica brick, and this is responsible for an increase of 20% in steel production and a fuel saving of 10%. One speaker from personal observation said that he believed the reports were correct. He had seen one such roof after 300 heats, with only 2 in. of the thickness gone. The wear had been very uniform.

Since temperature is the most important factor in steel making, one speaker called upon manufacturers of refractory materials to redouble their efforts to develop economical materials for temperatures considerably higher than those in use today. The present demand for something that will stand higher temperatures, resist erosion, retain shape under pressure and temperature variations, and not be prohibitive in cost, was considered a healthy sign. To achieve such results will require close cooperation between the makers and the users of refractory materials.

Instrumentation

On the subject of "Instrumentation of Open-Hearth Furnaces" one speaker gave his experience when running under semi-automatic control and compared it to fully automatic control. With fully automatic control, 10,971 more tons were produced in comparable campaigns, 53 additional heats were made, fuel was reduced by 2 gal. of oil per ton, and maintenance cost reduced 1.3¢ per ton. Other operators also reported decided savings in fuel and reduced maintenance costs; savings in fuel ranged from 2 to 15%.

Installation and care of the various instruments is worthy of considerable attention. One installation is housed in an air-conditioned room, and if, for some reason, the air-conditioning apparatus fails to function, the instruments show the effect.

The "Ray-O-Tube" pyrometer for taking bath temperatures was illustrated by slides showing a portable mounting for the indicating instrument. Temperature is measured by inserting a double tube 12 to 18 in. into the bath. It is made of an outer tube 2 in. in diameter, inside which is a centrally spaced tube 1¼ in. in diameter. Slag and metal are kept out of the

assembly by means of compressed air and it is good for about 100 observations. Temperature readings are obtained in 10 to 12 sec.

Openhearth Metallurgy

Grain size control proved an interesting topic under this general classification. Aluminum combined with iron as ferro-aluminum, or an alloy of iron, silicon and aluminum seemed to be preferred to ingot aluminum; the use of aluminum-zirconium-silicon and ferrotitanium was also reported. One speaker thought it had not been definitely proven that aluminum produces "dirty" steel; in his opinion each heat must be melted to a definite grain size, and temperature at tap is a very important factor. As to the best place to add the aluminum — the ladle or the molds — the general practice reported is to use part in each. From ⅔ to ¾ the expected requirements are usually added in the ladle and then the mold addition is regulated to the desired rimming action.

Commenting on the practice of deoxidizing forging quality steel of large grain size, one speaker thought it best to have one furnace practice and then regulate the grain size by ladle additions. As to possible benefits to be obtained by using more than the usual amount of 15% silicon-iron, it was thought that amounts giving over 0.10 to 0.12% silicon in the ladle analysis did no good. From the opinions expressed, the use of silico-manganese in forging steels seemed fairly general. It was the belief that it produced cleaner steel.

In making a 0.07 to 0.09% carbon rimming steel, it was the consensus that the heat should not be ored too closely; a better steel would result if carbon is brought down from 0.12 or 0.15% by the use of rods or green poles, or by allowing the heat to soak down. In some cases, the heat was finished by using a spiegel reboil. Rimming a 0.20% carbon steel was held to be a rather difficult matter. One suggestion was to go to 0.08% carbon and recarburize with coal.

Use of automobile scrap when making extra deep drawing steel sheets is generally avoided. Alloy contamination is the main objection. However, the effect of copper residual and copper additions on the rimming action of rimmed steel was, in the main, believed to have little if any influence. Opinions seemed to vary somewhat as to the effect of high or low residual manganese. One thought that, in the end, the result would be the same. Another thought that 0.15% residual manganese was the limit, and that 0.20% gave a sluggish rimming action.

A 2 to 3-in. rise in a rimming steel ingot was held to be an undesirable feature, regardless of how it may be produced. Such ingots do not possess the required skin thickness.

One speaker believed a rectangular mold produced better rimmed steel ingots than a square mold. Another thought that, aside from the increased cost due to lower mold life, lightly corrugated molds are better than straight-sided molds. In general, molds with a small corner radius were preferred; they give less trouble from corner cracks. Cold molds are to be avoided; they should be hand warm.

Tapping heats at too high a temperature is apt to produce thin-skinned ingots with blowholes close to the surface. On the other hand, tapping too cold produces dirty steel.

Discussion of various methods to control the FeO content of openhearth slags indicated this to be a subject of much interest. Working to a predetermined percentage seemed to be the usual aim. Data obtained by plotting the ratio of FeO in the slag to the FeO in the steel against the lime-silica ratio seemed to indicate that the amount of FeO in the steel is influenced by the lime-silica *ratio* more than by just the percentage of FeO in the slag. Raising the FeO by lime additions and lowering it by the addition of silica was one method of control mentioned. In another case, the FeO was adjusted by lime additions during the melting period, and it resulted in little trouble with either high or low FeO. In still another case, roll scale was used to raise the percentage of FeO and silica to lower the percentage. The "pancake" slag test was believed by some to indicate very accurately the lime-silica ratio.

In regard to the effect of the amount of limestone charged on the quality of the steel, one speaker thought that steel made under a slag containing less than 42% CaO would be of poor quality. The experience of another was that, when the limestone charge was lowered, the quality of the steel went down. The use of a high limestone charge automatically increases the lime-silica ratio, which makes the practice more fool-proof.

Securing a good run-off slag is a matter of proper charging, adding the hot metal at the right time and in the right amount, a correct amount of ore, scrap properly charged to hold down the lime and prevent it from getting into the flush-off slag, and correct temperature.

Nature of Bonding in Metal Compacts

By GREGORY J. COMSTOCK
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Handy & Harman, Bridgeport, Conn.

In the last issue of Metal Progress, in the article entitled "Metal Powders: Characteristics and Products" it was emphasized that *two* major considerations would form the basis of any development in this art — namely, the properties of the powder and the nature of the bond — and some general remarks were made on the first of these. It will now be endeavored to discuss the nature of the bond. In its finer aspects this is very involved and little understood. Sykes, who can certainly speak with authority on this subject, has said:

"While the past 25 years have contributed a valuable store of working knowledge in the field of powder metallurgy, many of the process controls are derived entirely from experience and are not as yet finally explained by specific physical or chemical phenomena."

True, this is a general statement, but I feel sure that there can be no criticism for applying it either to particle-to-particle bonding or to the cementing action which takes place in those powder products which acquire their strength and cohesion as the result of the formation of a molten constituent. Certainly both of these types of bonding have their undiscernible aspects, although considerable light is periodically being shed upon them.

Some examples will now be given for illustration.

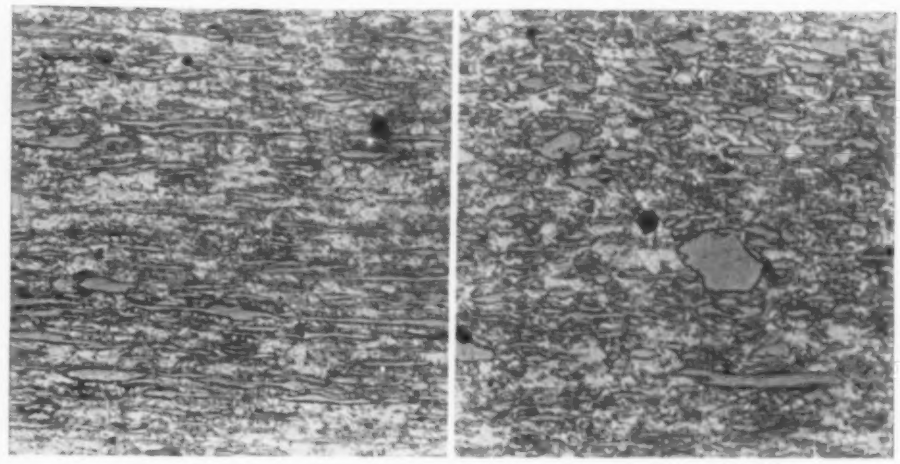
When two slabs of fine silver are placed one upon the other and are heated for a short time to temperatures below the melting point, it will be found that they adhere to one another at their points or surfaces of mutual contact. If the silver slabs are pressed tightly enough together to deform them when they are heated, or if they have been pressed previous to heating so that their contacting surfaces conform to one another, the area of contact is increased and the bonding effected during heating is naturally more complete.

Fine silver powder pressed in a suitable mold will result in a compact form of considerable strength and density. The particles are soft and ductile and are deformed to a close-packed arrangement without difficulty, providing the air in the mass successfully escapes. Heating compacts of this kind, to temperatures below the melting point of silver, results in the bonding of their particles one to another at their mutual points or surfaces of contact. Alternate mechanical deformation and heating produces new contact surfaces between the particles and bonds them so that eventually — if the operations are continued — each silver particle entirely conforms to and is completely bonded over its entire surface area to its adjacent particles. The structure then closely resembles the intercrystalline bonding of a cast, worked and heat treated product.

Iron and silver are, broadly speaking, regarded as having no affinity for one another; they are practically immiscible, either in their molten or in their solid states. However, recent investigations indicate the possibility of their forming some stable alloys consisting of very small but appreciable amounts of silver in iron and iron in silver. Proceeding as we did above with slabs of silver, placing a slab of iron on a slab of silver and heating them without melting but drastically deforming them while hot, a strong and satisfactory bond is formed.

When mixtures of iron and silver powder which have been compacted and heated to temperatures somewhat below the melting point of

either, a bond is produced between the silver and the iron particles which is not unlike that developed between the silver particles of the previous example. Alternate mechanical working and heating again produces structures which are suggestive of the intercrystalline bonding of cast metal.



Microstructure at 100 Diameters of Ductile and Strong Metal Made of 80% Silver and 20% Iron Powders. Pressed, Sintered and Cold Worked to 0.093-In. Gage. Longitudinal section and transverse section, left and right, respectively

Yet a third example: Silver has no affinity for carbon in any of its forms. A slab of silver placed upon a graphite slab shows no tendency to bond with it when the assembly is heated. Mixtures of silver and graphite in powder form, which are pressed and heated below the melting point of silver, display a limited amount of strength and cohesion if the silver is present in major proportions. When the graphite content does not exceed 7 or 8% by weight, such mixtures can be delicately manipulated to afford a certain limited amount of workability. Repeated mechanical deformation and heat increases this workability and eventually produces structures which are not unlike those of a cast product. Finer examination, however, indicates that the strength of this material may be explained by the bonding of the silver particles one to another and the formation of a strong and continuous silver network merely containing mechanical inclusions of graphite particles.

At the opposite extreme, silver and copper have a marked affinity for one another. They are miscible in all proportions in their liquid state and form an eutectic consisting of 72% silver and 28% copper which melts at 1435° F. When a slab of silver and a slab of copper are placed one upon the other and are heated for a short time to a temperature of 1435° F. or slightly above, it will be found when they are cooled and examined that they adhere to one another and that a strong bond has been formed. This bond consists of the eutectic which apparently was formed at the points or surfaces of contact, melted and permitted the two slabs to come more intimately in contact with one another, a progressive action forming new molten eutectic. When this action is stopped at the correct point, a very strong union may be expected.

Silver and copper in powder form, which are pressed in a suitable mold and heated, display particle-to-particle bonding which is either one of two types depending upon the temperature. If below 1435° F., it resembles the silver-to-silver adhesion of the first example. Alternate mechanical working and heating, below the melting point of the eutectic, produces the complete bonding suggestive of cast products. If the temperature exceeds 1435° F. another type of bonding is observed, which evidently involves the formation of the molten eutectic, and the proportions of the silver and copper present become a factor in the ultimate structure. These structures strongly indicate the formation of a molten eutectic, the diffusion of which into solid solution with the excess metallic component present leaves voids as the result of this migration. A certain amount of the eutectic cements the excess undissolved component together if the proportions are favorable for this action.

These practical examples of bonding have been selected as they can be used to demonstrate specific bonding tendencies of one metal — silver — both in the massive and in the powder form, first with itself, secondly with a metal for which it has no affinity, third with a metalloid with which it does not combine and finally with a metal with which it has a marked tendency to alloy and with which it forms an eutectic of known characteristics. Silver has been chosen for illustration because it is particularly adaptable for such bonding as the result of its nobility, malleability and the insta-

bility of its oxide at moderately elevated temperatures. Reference to the effects of oxide films and other bonding preventives have been omitted as have discussions of several of the manipulation procedures which are essential for effecting these bonds. Care has been exercised, however, to describe accurately the final product which can in each case be secured with good practice.

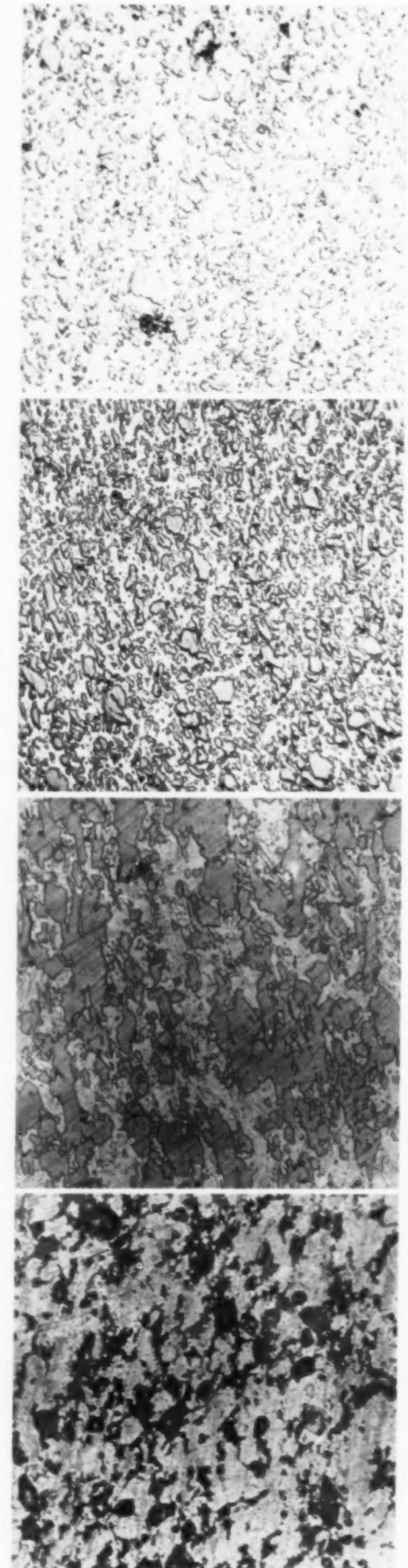
Specific Effect of Pressure

What are the mechanics of these unions? It seems reasonable to assume that the bonds developed by the small, conforming powder particles are of the same general character as those which are responsible for the bonding of the more massive slabs of the same metals under similar circumstances. *Pressure* and *heat* have been required to effect bonding in each of these examples. What are the functions of these two essentials for practical bonding?

Is the effect of pressure, or its residual, only that of conforming powder particles to one another so that they present contacting surfaces for bonding by some other physical phenomena? It would appear that this is the principal function of pressure in the bonding of the slabs, as light sheets of silver or even fine wires of that material will similarly bond at points of light contact, if they are heated without pressure.

Pressure is commonly applied to metal powders in either one of two sequences with respect to the heating operation. In the cold press process the powders are compacted cold; in the hot press process heat and pressure are simultaneously applied. In the former the powder particles have, therefore, been subjected to cold deformation (providing they *are* deformed) and in subsequent heat treatments might be expected to recrystallize in accordance with laws which govern that phenomenon. It will be remembered that in general the recrystallization temperatures are lowered by increasing degrees of cold deformation. Should either surface recrystallization or intra-particle recrystallization be a factor in particle-to-particle bonding, pressure would then influence such bonding by affecting the temperature at which recrystallization would take place after cold pressing.

Hot pressing above normal recrystallization temperatures of the components, on the other hand, would not be expected to result in stressed particles but rather in an annealed condition. More deformation and better contact between particles might be expected — providing the



Transverse Sections of Ductile Bars of Contact Materials Made of Silver Containing 10%, 20%, 40% and 60% Nickel (Top to Bottom). Longitudinal sections show elongated grains or fibers which these views show cross-grain

temperatures were sufficient to promote plasticity under the imposed pressure. Experiments with slab assemblies illustrate quite graphically that pressure *is* an important aid to bonding. Pressure applied to hot assemblies (or to powders) is usually very effective in contributing to the continuity of the bonding which is developed without the formation of a molten constituent. It would appear, therefore, that the effects of pressure in promoting this type of particle bond is in a sense dependent upon its relationship to the effects of heat; that pressure applied under circumstances which produce cold deformation of the particle might be expected to effect bonding, providing recrystallization of stressed particles is a factor; that pressure applied to metal powders contributes to the completeness of the bonding between particles by promoting greater surface contacts between them, and that pressure is more effectively applied to hot powders than to cold.

Specific Effect of Heat

What is the function of heat in bonding without the assistance of a molten constituent? Only one hypothesis of which I can conceive satisfactorily explains the evidence of these and similar examples: Heat plays precisely the same role in assisting the formation of these powder unions that it does in the development, and especially in the maintenance, of the intercrystalline bonds of a cast and worked metal.

Intercrystalline bonds are initially produced by cooling from the liquid through the plastic to the solid state. Cooling from the plastic to the solid state is apparently sufficient for the propagation of atomic bonds between contacting metal surfaces. Plasticity, as hereinafter defined, is an essential condition for unions of this kind which are formed without the presence of a liquid phase — *not,* however, solely as a means of promoting more intimate contact between the metal surfaces, as W. D. Jones has erroneously concluded in his "Principles of Powder Metallurgy", but because the arrangement of atomic forces and the atomic mobility incident to plasticity are favorable for the propagation of atomic bonds between such intimately contacting metal surfaces.

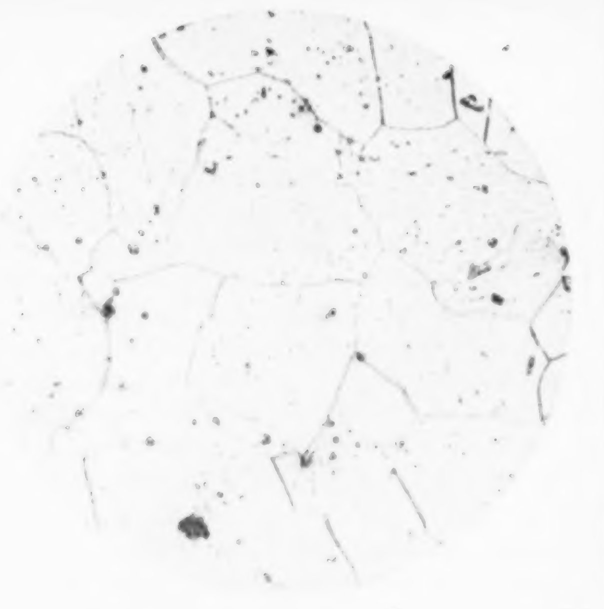
"Plasticity" is undoubtedly a poor term to employ in this connection as all metals may be said to possess a certain degree of plasticity in their solid state. Yet it is difficult to select a more satisfactory designation for that condition of atomic mobility evidently necessary for the production of lattice intermediates which will bond the surfaces of power particles. If by "plasticity" a condition of ready deformation is understood, and a condition of atomic mobility is the essential requirement, the term may stand for the purposes of this discussion as limited by the examples discussed. This definition will be more accurate, however, if it is understood also to involve the development of temperatures which are above the recrystallization temperatures of the materials under consideration.

I have a strong suspicion that recrystallization phenomena have a great deal to do with the formation of unions of this kind; that plasticity and the temperatures which in most cases are required to promote it, in effect only involve those temperatures which are required to promote recrystallization and the limited plasticity incident to it; that bonding of this type does not take place at temperatures below those necessary for recrystallization effects. Time, which is a factor promoting practical results as well as film distortion, intimate contact and other associated practicalities, undoubtedly confuse the issue. Adequate discussion of the function of heat is a difficult matter unless some such limited use of the term "plasticity" may be employed.

If plasticity, in this sense, is a rough indication as to whether or not this type of atomic bonding is to be produced, additional heat should not be required for the union of metals which are plastic at ordinary temperatures, high temperatures should be required for metals that maintain their strength and resist deformation at elevated temperatures, and no true unions of this character will be made between crystalline and amorphous materials.

The bonding at room temperature of malleable proof-gold in powder form when its particles are moderately pressed together is a well-known example of "cold welding" which can be cited in support of this theory. The ductile tungsten process is an excellent example of the high temperatures required to effect bonding of this type between similar particles of a metal which retains its non-deforming character at elevated temperatures.

If this hypothesis is to be tenable there should be difficulty in effecting this type of bond between a soft malleable metal having a comparatively low melting temperature (such as silver) and a hard and rigid refractory metal (such as tungsten). The silver might be



Pressed and Sintered Iron. 500 ×. Nital etch

expected to approach melting before the tungsten became sufficiently plastic to permit this character of bond being formed. Such *is* the case; effective bonding between silver and tungsten in powder form must be conducted within a very narrow range of temperatures. Likewise graphite does not bond with silver and is only included in a network of that material when properly manipulated in powder form.

Molten Cement

What are the mechanics involved in the other general type of particle union where a molten constituent acts as a cementing medium?

There appears to be an essential similarity between all types of metallic unions which may or may not prove to be significant. The essentials for bonding metal with a molten metallic cement seem to be that the unmelted constituent shall possess at least a certain degree of metallicity and that it shall be soluble, even if only to a limited extent, in the molten constituent or have a tendency to combine with it. Under these conditions solution or alloying essentially involves the formation of new atomic arrangements and fulfills the conditions which prevail during the formation of the initial intercrystalline bonding of cast metal. I submit that as these conditions are similar and the effect the same, the unions are identical.

Is the apparent similarity, therefore, which exists between properly bonded powder particles and the intercrystalline bonding of cast metal real or only an illusion? If both of the two general forms of powder particle bonding which have been mentioned result from the fixation of cohesive atomic surface forces in some such manner as has been suggested, they *are* the same.

It is extremely important to establish the accuracy of conclusions of this kind if only to permit the potentialities of applied powder metallurgy to be correctly evaluated.

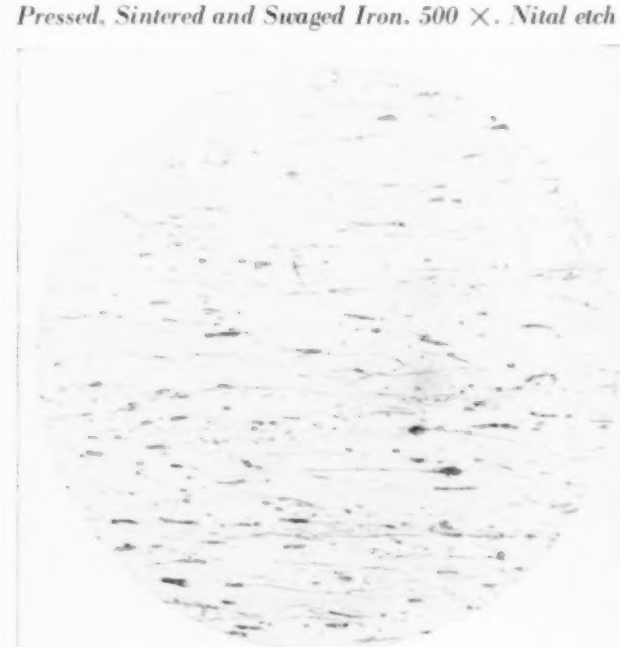
Iron Powders

Progress recently made in the commercial molding of iron powders now furnishes the strongest of incentives for establishing these potentialities in that field — one of the broadest applications of powder metallurgy. Iron parts can be molded from powders, consolidated by heat treatment, and coined or pressed to an accuracy of fine machining operations. Bearings, bushings, parts for minor mechanical assemblies, small gears and automobile hardware are being made with efficiency and accuracy and at a cost less than by any other method.

What physical characteristics can these molded iron parts be expected to display? Will the bonding reproduce the strength of the intercrystalline bonding of iron cast in similar shapes? Can such parts be regarded as exact substitutes for similar ones, cast of the same composition, or must they be accepted as being of the same shape but of necessarily inferior physical properties?

These are practical questions which require an answer before we can correctly envision the potentialities. If the bonding hypothesis which I have advanced is tenable, iron parts molded from powders can be made which exactly reproduce the strength and other characteristics of iron parts made by the old methods. The

Pressed, Sintered and Swaged Iron. 500 ×. Nital etch



advantages and economies of this new method of producing them to exact dimensions will not be reduced by the necessity for regarding them as being in any way inferior to a cast product.

In the normal processes of crystallization, extraneous material is rejected by the solidifying portion. In cast metals these rejects tend to accumulate in the boundaries between crystals, weakening the tenacity of these primary unions upon which the strength of the material is so dependent. Theoretically, at least, unions between film-free powder particles should not be subjected to this defect. The possibility, therefore, exists for producing powder products which are *stronger* than the same material in cast form, rather than weaker.

If iron parts can be bonded so successfully, what are the possibilities of similarly bonding *steel* particles when such fine particles become available? If such molding operations are cheaper than casting plus machining in the production of iron parts, may not similar methods also be economical for brass particles when that alloy and other non-ferrous alloy powders are ultimately produced in commercial quantities? More important still from the viewpoint of practical development, can the molding and consolidation of such alloy powder products be made to include some of the other special attributes of metal powder technique?

These special attributes include the possibility of producing pure metal forms or aggregates of materials which cannot be normally cast or worked or forged and which are difficult to shape by any process. Casting difficulties which have hitherto seriously retarded the development of super-tool materials are in some cases entirely eliminated by powder methods. Finely divided hard metallics can be included in thermally stable matrix by powder particle pre-arrangement, rather than by the chance distribution after precipitation or crystallization from a melt. Vacuum and controlled atmosphere heating is much easier to apply during the sintering of compacts than to the casting and molding operations; the use of additions to promote casting or to eliminate undesirable extraneous materials is not required. Unusual structural effects and local variations in composition are made possible by powder manipulations. It seems altogether reasonable to assume that these and other special attributes of powder metallurgy will eventually be applied both to the production of established materials and also to a large number of new materials.

Is Hardness Affected by Magnetization?

In 1929 Edward G. Herbert reported to the British Iron & Steel Institute that the hardness numbers of quench hardened and age hardened alloys such as steel and duralumin could be increased by exposure to electromagnetic fields. A supplementary article by him along these lines published in Metal Progress, April 1932, brought forth a note two months later by R. H. Harrington of the General Electric Research Laboratories, who found no change in the Rockwell hardness numbers of quenched high speed steels after exposure to a magnetizing apparatus. Various claims and counterclaims were made elsewhere, so the British Alloy Steels Research Committee recently authorized some work to determine the effect, if any, of high frequency electric currents on the properties of steel.

This work was done by A. G. Quarrell, R. Jackson and N. J. Petch under the direction of Prof. J. H. Andrew in Sheffield University, and published as Section VII of the Second Report of the Alloy Steels Research Committee (Iron and Steel Institute, Special Report No. 24, page 157).

The depth of hardness of carburized mild steel, the aging of carbon, nickel-chromium and 18% tungsten high speed steels, the tensile strength of carbon steel strip, and the impact value and grain size of carbon steel all formed the subject of critical experiments. In the majority of cases the results were negative, and in those few cases where some difference was observed between the untreated specimens and the specimens which had been subjected to the high frequency current, the investigators believe that such difference might be attributed to some extraneous circumstance, such as the incidental heating of the steel, other than the direct effect of the periodic electric and magnetic oscillations. The frequencies and magnitudes of the currents employed covered such a wide range that it can be concluded that *if* a high frequency current can have a beneficial influence upon the properties of steel, then the frequency must be very critical and will be determined by the particular conditions employed.

New Books

"What We Need Is a *Handbook*—"

A review of many
By GORDON T. WILLIAMS
Metallurgist, The Cleveland Tractor Co.

In recent years there has come forth a steady procession of handbooks for the metallurgist — in fact, the pace seems to be accelerating. The conscientious man who tries to keep at hand the best information available already has a shelf full of "handbooks". Many of them are so called only by special dispensation, as for instance the 1939 ⊕ Metals Handbook, 6x9 in. with nearly 1900 pages and weighing 4.266 lb., which requires only a list of contributing authors and a subscription selling scheme to become an encyclopedia, and no disparagement intended!

Perhaps we would be justified in giving a few moments' consideration to the general situation in the field of handbooks useful to the metallurgist. They are of several types and intended for various purposes; some appear to hit their target well while some miss it fairly completely, if we may make assumptions as to the intention. The conventional meaning of the word "handbook" is a volume — usually of small page size — designed to cover a selected, relatively broad division of knowledge or activity, and cover it in such general fashion that everyone will find *some* questions answered, and, presumably, no one will find *all* the answers he needs. As the intended field is limited or the probable user more narrowly selected, the specific usefulness of the handbook should increase. A good example of the latter suggested by the Editor is Searles' "Field Engineering", found in the coat pocket of every surveyor of the last generation.

Then, too, there are two general kinds of reference books — those of the educational, encyclopedic type containing treatises on selected subjects, or those of the tabular, dictionary type, wherein the answer is given but not the philosophy or method of solution. Since much metallurgical knowledge cannot, yet, be tabulated or similarly summarized, the usual practice in present-day reference books is to balance the educational articles and the classified matter.

As may be easily understood, the real problem confronting the builder of a handbook is not what to put in but what to leave out — where to draw the line between must, should, and shouldn't. For example, every metallurgical handbook seems to carry a table of weights of steel bars, but none has a table of the electromotive force generated by standard thermocouples at increasing temperatures. The duplication of effort and cost of having the same or a similar weight table in every handbook must be considerable, but, looking at it from the angle of the designer of the book, how can he justify leaving out a table often needed, and whose omission might cause a worthy book to be subordinated or forgotten? Of course, such books as "U. S. S. Carilloy Steels", "Republic Alloy Steels", or "Bethlehem Alloy Steels" are designed to be helpful and useful — but must above all make the user think of the sponsoring company, and the oftener it is used the oftener such thought registers, and the more successful the handbook. Every such work is sent forth in the hope it will be indispensable to the recipient, that it will be just what he needs in his daily work.

Please note here that the present reviewer has no thought of criticizing the idea or execution of any of these handbooks — each is an excellent job, and very useful indeed. But it is manifestly impossible for one reference work simultaneously to meet the needs of the metallurgist in tractors, oil well equipment, and shoe machinery! Further, each of these "alloy steel" handbooks, in order to justify its cost, has to be educational, so that the non-metallurgical user may be elevated to the necessary comprehension. Surveys of applications and operations are given in the hope of aiding the steel user to get the most out of the steel best suited to his requirements.

The other side of the picture is that no handbook can hope to be ideal for any individual; there is nothing quite as good *for him* as the reference notebook he can build for his own needs. He won't bother about the ubiquitous weight table, or S.A.E. steel specifications;

he may not even have interest in data his fellow members find indispensable; maybe this private handbook won't even have the properties of heat treated carbon steels in it! But from one source or another, as forced search uncovers it, the individual will collect tabular and miscellaneous data that he needs — and the total will be a collection that *he only* needs. Many a reader of METAL PROGRESS has no doubt remarked about some of the data sheets the editor gives us, "What on earth does anybody want that for?" — but each probably has value to some readers.

The only consolation that can be given to the man who is disappointed in one of the above-mentioned alloy steel handbooks is that maybe one of the others will suit him better. It is my feeling, however, that he will not and cannot hope to be satisfied with any but his own loose-leaf handbook, and not entirely satisfied even with that.

The amount of valuable information summarized and imparted by such freely distributed books as the three recent ones by our major steel producers is tremendous. A further excellent reservoir of data lies in the "special alloys" books, like "Nickel Alloy Steels", "Vanadium Steels and Irons" and "Molybdenum in Steel". With sincere respect for their merits, however, it should be remembered that "an ax must be ground" if the publication is to justify its cost. Consequently, one needs to remember that there is another side to some of the pictures presented. However the general articles in these

Photograph by W. A. Silliman

Metallurgists' Handbooks

Nickel Alloy Steels; International Nickel Co., New York, 1934.

Vanadium Steels and Irons; Vanadium Corp. of America, New York, 1938.

Molybdenum in Steel; Climax Molybdenum Co., New York, 1938.

Molybdenum in Iron; Climax Molybdenum Co., New York, 1938.

Bethlehem Alloy Steels; Bethlehem Steel Co., Bethlehem, Pa., 1935.

U.S.S. Carilloy Steels; Carnegie-Illinois Steel Corp., Pittsburgh, 1938.

Republic Alloy Steels; Republic Steel Corp., Cleveland, 1938.

Forging Handbook, W. Naujoks and D. C. Fabel; American Society for Metals, Cleveland, 1939.

Cast Metals Handbook, 1936 Edition; American Foundrymen's Association, Chicago.

Welding Handbook, 1938; American Welding Society, New York.

Metals Handbook, 1939 Edition; American Society for Metals, Cleveland.

In the foreground, the man's own notebook; on the wall, the "S" curve for high carbon steel, at the left, a channel of communication to secure missing information from nearby friends.

books are outstanding, and constitute real and even unique contributions to the American metallurgical literature that is available in this year of grace.

Then there are the encyclopedic reference books — the ⚙ Metals Handbook, A.W.S. Welding Handbook, A.F.A. Cast Metals Handbook (all these are cooperative, technical society works representing a compilation of carefully scrutinized articles and data by authors selected from the best available regardless of specific allegiance), and the new Naujoks and Fabel "Forging Handbook". These are designed to cover their respective fields so comprehensively that an approximate or partial answer to any pertinent question may be found, together with the educational approach necessary to comprehension thereof. Comparatively little tabular matter is given in them, the assumption being implicit that other handbooks will be available, and reasonably so, too. Although every metallurgist will at some time need a five-place logarithm table, should one be included in each of these books?

As handbooks go through repeated revisions, they tend to drop superfluous words, to increase in breadth of territory covered, and to correct major and minor errors. The general acceptance of ⚙ Metals Handbook as the outstanding metallurgical reference work can be credited most largely to the experience of several editions and the many years of work on which the 1939 edition is based.

Going but slightly afield from strict metallurgical work, there are such reference books as the "Handbook of Chemistry and Physics" or the similar "Handbook of Chemistry", the "S.A.E. Handbook", "Chemical Engineers' Handbook", "Procedure Handbook of Arc Welding Design and Practice", and, daily necessary to the shop man, Marks' or Kent's "Mechanical Engineers' Handbook".

Only a very loose definition could classify all the works mentioned as handbooks, and to complicate the situation even further, we must remember that such storehouses of organized knowledge as the "Alloys of Iron Monographs" or "The Book of Stainless Steels" may be handbooks to someone — so: "What *is* a handbook?"

"Of the making of books there is no end" — and may there never be an end to the publication and revision of handbooks. May we ever be hopeful that the perfect handbook for *us* will appear — and may we clearly understand why it won't!

Heat Treatment

Introduction to the Study of Heat Treatment of Metallurgical Products, by Albert Portevin. 216 pages, 6x9 in., 69 diagrams. Penton Publishing Co., Cleveland, Ohio. $5.00.

In sorrow it must be recorded that the Penton Publishing Co. has been "sold a bill of goods" not, I hasten to add, by the gifted French author but by the anonymous translator. From considerable personal experience, punctuated with a too high proportion of failures, the present reviewer knows how difficult it is to make a good translation of a foreign technical publication — French, for instance. Not only must the translator be familiar with idiomatic French but also with idiomatic American (especially the metallurgical idiom) and if the work is at all advanced, as this book is, must know a great deal of metallurgy as well. Whatever the present translator's knowledge of French may be, he is obviously not a writer of the American language nor a metallurgist. Too bad no mention is made on the title page of the fact that this book *is* a translation; few readers will know that Professor Portevin speaks and writes no English, and will therefore accuse him of such misdemeanors as this one on page 88:

> "In order to conclude the characterization of the various quenching states of the same steel, they will be defined by their hardness, Δ, and will be added to the characteristic curves, the curves of equal hardness, Δ, isoscleric curves, the level lines of surface Θ_c, V, Δ which represents a crest line, the projection of which is the maximum hardness curve A'B'."

Dimly one may see that the author is talking of a three-dimensional figure whose coordinates are Θ_c the quenching temperature, V the quenching velocity, and Δ the resulting hardness, and the critical quenching rates for a given steel in a given size are represented by a crest, ridge or divide on that surface.

In view of the lingo in which it is written the book may be recommended to advanced students of metallurgy (both ferrous and nonferrous) principally because it contains a systematic exposition of the fundamentals of heat treatment, and also because it will require intense mental concentration to discover what the French author was really saying to his French students. If there is anything in the ancient pedagogical idea that you learned best by the hardest work, then this book will do much for your metallurgical polish. E. E. T.

Critical Points

Notes by the Editor

New York City — Spent an hour in the busy press department of the World's Fair trying to find some interesting pictures of unusual metal construction, other than the over-publicized "theme center", a fruitless search because the other large structures were erected by various governments and corporate exhibitors. The novel views of structural steel which were available, therefore, depended on bizarre photography more than anything else. A considerable amount of metal, both in natural color and enameled, is used in numerous large murals and bas-reliefs; likewise heroic statues of formed and welded stainless sheet surmount Henry Ford's and Joseph Stalin's buildings. The stainless steel and the copper covering on buildings of U. S. Steel Corp. and General Electric Co. give an air of quality and substantiality among hundreds quite obviously of temporary construction.

Metal at the N. Y. Fair

See this Fair first at night, when darkness hides much ugliness, the wonderful lighting transforms bizarre shapes into fairyland, and variations in color or from light to shade pick out and intensify decorative features or adorn much flat surface blank and uninteresting in sunlight. By day, the perisphere looks like a ball of mud; by night, a heavenly orb.

Schenectady — Traversed in one day almost the entire span of metallurgy, from medieval through pre-War to ultra-modern. Prof. Mortimer Sayre of Union College showed me some of his old books, among them being Agricola's "De Re Metallica" (1556) and the Hoovers' re-creation of it. "Re-creation" is written advisedly after comparing the typography and illustrations of the two books separated by nearly four centuries, and remembering my own failure to get a very good reproduction of an old engraving for a Metal Progress cover last December.

Leo ("Mul") Mulholland, engineer of tests of American Locomotive Co. and first chairman of Schenectady Chapter ⊕, brought matters closer to date when talking about high speed steam engines and the problem of making — or rather maintaining — large forgings for axles and siderods. Working stresses long since have gone beyond the capacity of soft carbon steel, more or less fool-proof, and steels with as high as 0.40% and even 0.55% carbon have been utilized. Railroad men have avoided quenched steels, knowing that their shop crews and equipment are usually incapable of properly re-heat treating these forgings after a hot box or major repair, yet Mul pointed out the undoubted fact that a 0.40% carbon steel requires just as careful treatment.

Powder metallurgy, especially iron, was the ultra-modern item uppermost in the mind of LeRoy Wyman, metallurgist in General Electric's Research Laboratory. Iron powder of high purity is required for Alnico magnets, and this is now available as a byproduct of an electrolytic recovery plant installed to mitigate a nuisance from spent pickling liquors. Wyman has great faith in the commercial possibilities of iron powder made by direct reduction of a pure ore (such as a 68% iron concentrate from magnetite). Such a concentrate does not need to be pure Fe_3O_4 to be usable; for instance, an iron powder analyzing only 96% metallic iron (balance gangue) can develop 35,000 psi. tensile strength in 0.505-in. test pieces. The manufacturing method is to compact the iron powder by relatively light pressure, sinter the compact in reducing atmosphere, hot press or coin the part from the sintering heat, and control the subsequent slow cool. Commercially its uses will be for pressings to substitute for cast-

Powder Iron Compacts

ings expensive to machine — that is to say, the powder compacts will substitute for die castings. Extent of such applications will depend somewhat on the cost of the powder, but even now iron rivets (of all common, easily made things!) are being manufactured for own use and for sale by one of the automotive subsidiaries.

Memo: Wyman's forte is duck pins; for confirmation see Truman Fuller.

Cleveland — The Editor frequently invites himself to lunch with Carl Swartz at the cafeteria maintained in its characteristic exemplary fashion by Cleveland Graphite Bronze Co., for he finds both the food and the conversation excellent. One byproduct of these visits was the picture story on the manufacture of babbitt bearings published last June, a minor scoop for Metal Progress and our first technical publication from this enterprising firm. Those who saw that issue may recall that endless strip steel is cleaned, tinned, a layer of babbitt cast continuously on the advancing surface, and the excess babbitt milled off. The resulting bi-metal strip is then ready for blanking, forming, and broaching into a steel-backed bearing.

Composite Metal for Difficult Services

Swartz now tells me that the process is suitable for any combination of metals yet tried, even in multiple, the only apparent limitation being that the layer being cast-on be of lower melting point than the foundation surface. As dissimilar metals as lead and steel are readily bonded by this method. Likewise bi-metals or tri-metals, made to uniform layer thickness by this process, may be cold rolled under controlled conditions, a stiffer steel backing deforming in exact proportion to a softer brass or bronze top layer, even down to cardboard thinness, the weld being uninjured and no bald spots appearing where the backing metal breaks through its jacket.

One interesting and unpredicted success has already been achieved in the form of a "tri-metal" bearing. The type described last year, and used by the million by the automotive industry, has perhaps 0.025 in. of babbitt on 0.050 in. steel. This new bearing has on the order of 0.005 in. of babbitt, 0.020 in. copper-lead alloy and 0.050 in. steel. The staff at Cleveland Graphite Bronze is still wondering why this combination prevents or postpones that fatigue fracture at the running surface of the babbitt, and John Anthony suggests that the thinness of the babbitt layer is an important factor, augmented by obscure relationships between the physical properties of the babbitt, bronze and steel — notably the ratios of coefficients of expansion, the differences in their thermal conductivities, and moduli of elasticity.

Newark — "Blessed is he who can convert his mistakes to his own advantage" is a free translation of a comforting verse in the apocryphal Koran by our own expert on the minor Arabic dialects and Col. Lawrence's "Revolt in the Desert". So is the Editor twice blessed! More than a year ago he was gently taken to task by Charles Mantell of Brooklyn, consulting engineer and expert in the minor metals, for omitting the Driver Co.'s trade name "Tophet" from an editorial note on improved resistor elements, seeing as how the two other important brands "Chromel" and "Nichrome" *were* mentioned. At that time Mantell offered an inspection of the operations at Wilbur B. Driver Co.'s plant in Newark, where he spends much time as technical director — an invitation just recently accepted.

Electrical Wires of All Sorts

Of prime interest is the amount of inspecting and testing required on electric and magnetic alloys, step by step from ingot to spool of finished wire. The men seem to put in most of their time measuring and testing the output of their machines.

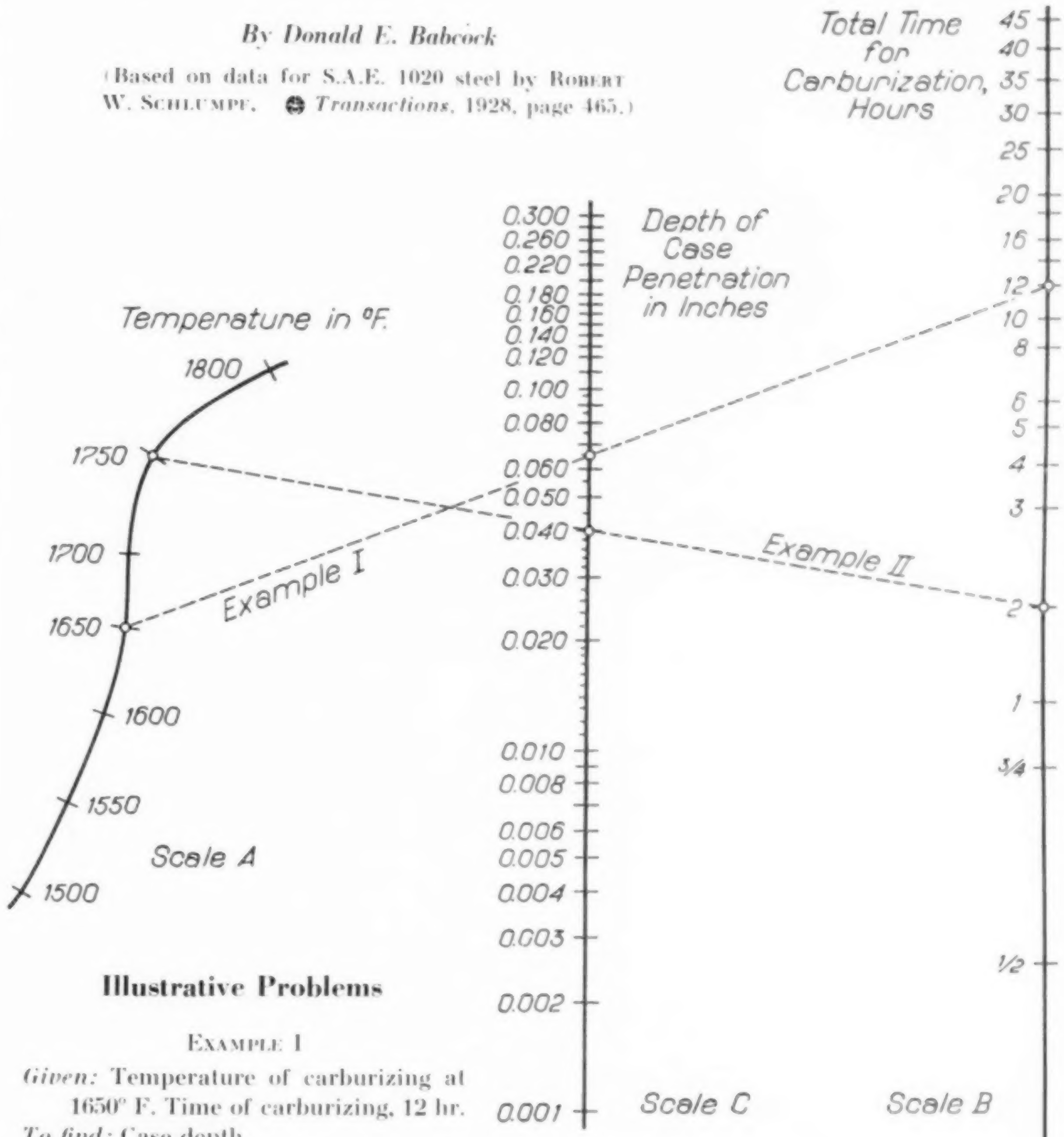
Mantell pointed out the numerous places where changes in manufacture have resulted in a 30-fold improvement in the life of resistance alloys in the last five to seven years, as shown by Francis Bash in an article in Metal Progress, February 1938. About 60 separate alloys are in production in the Newark plant, some with a multiplicity of electrical characteristics and an unlimited variety of sizes and insulation. It is therefore important to know much about the nature of each ingot before any work is done on it, so two "finger" castings and a wedge shape are poured (when the ingot is cast) for checking analysis and electrical characteristics, and for hot flattening to estimate its workability. Among many requirements for resistance wire one apparently simple one has given a lot of trouble: A closely wound helix of N turns when pulled out like a spring to D distance must acquire a *uniform* set so the coils of the resistor in a heater channel will have correct spacing. Try that on fence wire!

The gamut of operations is illustrated by heat treatments ranging from bright annealing for zero surface change to putting a layer of carbon on nickel strip, tight enough so mechanical forming into vacuum tube plates will not damage it. In the latter case the nickel strip, after air annealing for softening and roughening the surface, passes up and down a water-sealed vertical furnace where a carefully prepared atmosphere (mixture of propane and butane bubbled through liquefied illuminants) reduces the nickel oxide and deposits the required tight layer of lustrous carbon.

Alignment Chart for Case Depth

By Donald E. Babcock

(Based on data for S.A.E. 1020 steel by ROBERT W. SCHLUMPF, Ⓐ *Transactions*, 1928, page 465.)



Illustrative Problems

EXAMPLE I

Given: Temperature of carburizing at 1650° F. Time of carburizing, 12 hr.

To find: Case depth.

Procedure: Draw line I from 1650 on Scale *A* through Scale *B* at 12 hr., read case depth on Scale *C*.

Answer: 0.065 in.

EXAMPLE III

To determine carburizing temperature when time and case depth are given, reverse the order of operation given in Example II.

EXAMPLE II

Given: Temperature of carburization at 1750° F.

To find: Time necessary to obtain a case depth of 0.040 in.

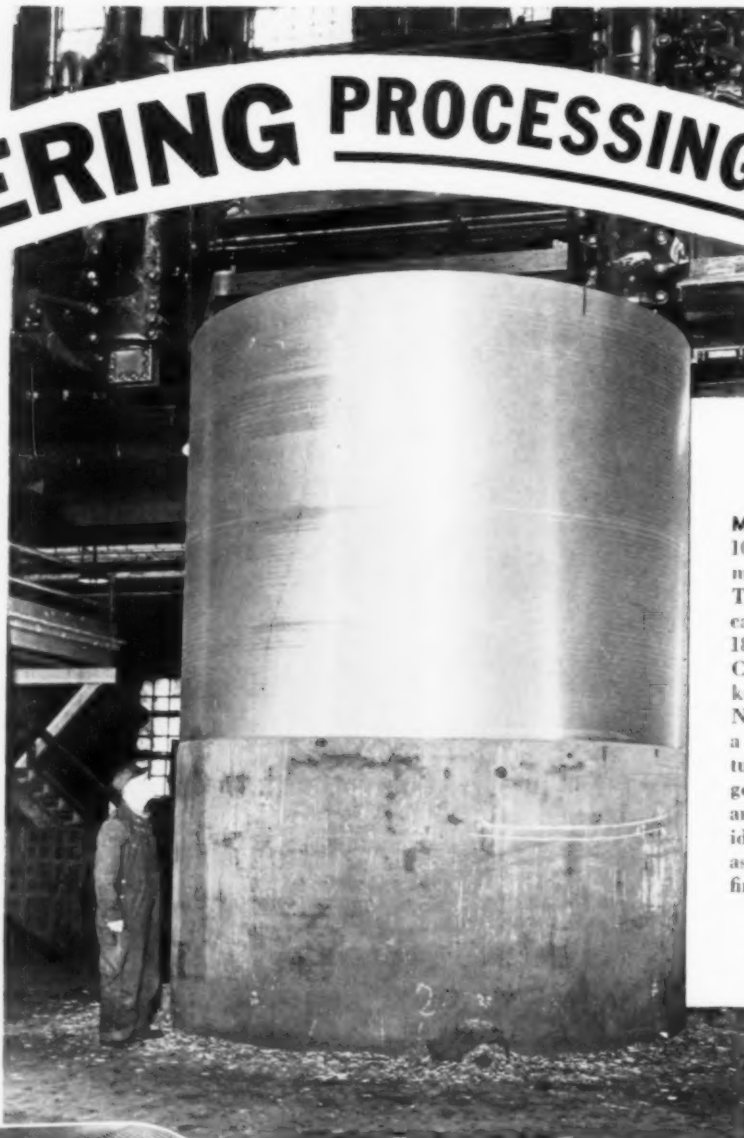
Procedure: Draw line II from 1750° F. on Scale *A* to 0.040 in. on Scale *C* and extend through to Scale *B*.

Answer: 2 hr.

LOWERING PROCESSING COSTS

... on
GOLD, SEWAGE and PAPER PULP

... with
NICKEL CAST IRONS



MIRROR-SMOOTH this 108,000 lb. drier shell presses moisture from paper pulp. To assure uniformity in this casting, 12 ft. in diameter and 18 ft. overall length, Allis-Chalmers Mfg. Co., Milwaukee, added 1% Nickel. This Nickel cast iron developed a dense, close-grained structure throughout, which, together with its uniformity and machinability, makes it ideal for such applications as this, where a very smooth finish is required.

*Ni-Resist—Reg. U. S. Pat. Off. by The International Nickel Company, Inc. — #278,180

*Ni-Hard—Reg. U. S. Pat. Off. by The International Nickel Company, Inc. — #281,986

GOLD MINE "IN THE BLACK." Even in gold mines, operating costs must be kept down. Ball mill liner costs were *halved* when the Wendigo mine in Kenora, Ontario, used Ni-Hard,* an exceptionally hard and wear resistant Nickel cast iron, for liners in their ore grinding mill. These liners, cast by the Vulcan Iron Works, Winnipeg, handled more than *twice* the tonnage reached by previous liners of an unalloyed material. Reduce processing costs by specifying Nickel cast irons for hard jobs in your plant. For practical information about money-saving applications of Nickel alloyed materials in your industry, please write to the address below.

LASTS 10 TIMES LONGER. In one service test, Ni-Resist,* the special corrosion-resistant Nickel cast iron, withstood acids and organic compounds encountered in raw sewage 10 times longer than plain iron. To cut processing costs in modern sewage disposal plants, this Comminutor grinder shell is cast from Ni-Resist for the Chicago Pump Co. These precision castings, which withstand abrasive wear stoutly as they do corrosion, were produced by the Challenge Foundry Co., Batavia, Illinois.

THE INTERNATIONAL NICKEL COMPANY, INC., 67 WALL ST., NEW YORK, N. Y.

Correspondence from Home & Abroad

Immunity of Two-Phase Stainless Steels to Intergranular Attack

Letter from H. Hougardy
Research Laboratories, Deutsche Edelstahlwerke

KREFELD, Germany — So-called weld decay of normal stainless steel (analyzing 18% chromium, 8% nickel, 0.10% carbon) is well known. Regions alongside joints, where the metal had been heated to 1650 to 850° F. by conduction of heat away from the welds, are rapidly attacked by many reagents that have no effect on the rest of the metal. The cause of this trouble is also known to be the precipitation of chromium-rich carbides at the grain boundaries of the austenite when heated within the above-mentioned range, thus depleting their neighborhood of the chromium in solid solution necessary for corrosion resistance. The chromium-poor zone naturally no longer possesses the same resistance to attack as the actual original homogeneous alloy, and the material alongside the grain boundaries is corroded. This attack likewise sets up electrolytic action between the chromium-poor zone and the chromium-rich grain centers.

Now there are several possibilities of preventing this grain boundary dissociation:

1. The welded part can be heated to a temperature above 1825° F. so that the precipitated chromium carbide will again go into solution in the austenitic base metal. At the same time the chromium distribution reaches an equilibrium so that no further acid attack can take place. Rapid cooling then prevents re-precipitation of carbides.

2. Carbon content can be held to the lowest possible value. Observation and experience have shown that with a carbon content under 0.07%, the amount of carbide precipitated by the welding heat is small when the time of the welding action is short, so that no continuous chromium-poor zone will then form. If, however, a steel with, say, 0.05% carbon is held for a longer time — for example, 1 hr. — in the critical temperature range, then much carbide is precipitated, a continuous chromium-poor zone is formed, and grain boundary disintegration occurs. For this reason stainless steel exposed to corrosive media must either operate at a temperature below 575° F. or the carbon content must be held under 0.02%.

3. So-called carbide-forming elements can be added; tantalum, columbium and titanium have proven most effective. These elements form carbides which are practically insoluble in the Cr-Ni-Fe solid solution.

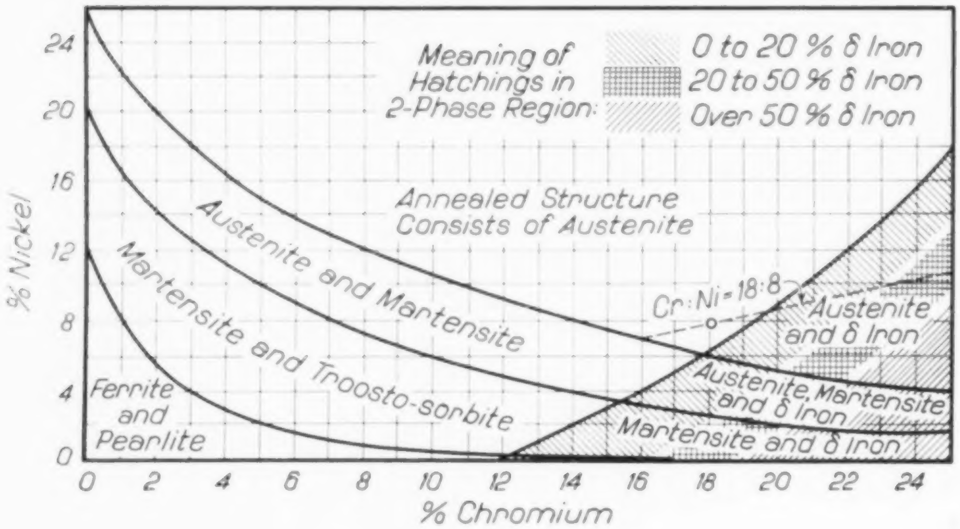
4. Chromium can be increased in percentage so that the microstructure contains a definite amount of delta iron (or alpha iron, either being the body-centered cubic space lattice). If such a steel, containing, for example, 0.10% C, 22% Cr, and 10% Ni and possessing 15% of delta is heated for a short time at about 1100° F., and then tested in a very corrosive reagent, it will be found to be corroded at the grain boundaries. Thus it has followed the same process as a normal 18-8 Cr-Ni steel. If, however, the steel is heated for a longer time in the dangerous range, the susceptibility to grain boundary attack steadily declines and, after a certain period of time, entirely disappears. A long heat treatment at moderate temperature thus "immunizes" the steel. R. Scherer first reported this phenomenon to the International Corrosion Conference in Paris, November 1938.

Such stainless steel sheet, with about 15% ferrite and 85% austenite in its microstructure, that has been annealed for a long time at 1100° F., can be welded with no change in its internal condition nor subsequent disintegration near the welds. Likewise it can be used in continuous operation at temperatures above 600° F.

The behavior of the steel described when tested in the dangerous range is given in the table on the next page, showing clearly the effect of carbon content, carbide-forming additions, and immunizing a two-phase steel.

Immunization of austenitic steels containing ferrite (alpha or delta iron) can be pictured in somewhat the following manner: First of all, as has been stated, carbon precipitates at the

Structural Diagram of Cr-Ni-Fe Alloys, According to Maurer, Modified to Show Relative Amounts of Delta Solid Solution in the Two-Phase Region



grain boundaries in the form of chromium carbide and forms a chromium-poor zone alongside the grain boundaries. On longer exposure to heat, the chromium diffuses from the center of the grains to their boundaries, and there the distribution of chromium gradually equalizes, so that the cause of the grain boundary attack is mitigated and finally removed entirely.

This redistribution of the chromium can be attributed to the action of the ferrite, for in single phase austenitic steels it does not occur, as can be readily seen in the first two columns in the table. The influence of ferrite can be explained as follows: *(a)* Ferrite possesses a higher chromium content in solid solution than austenite, and *(b)* chromium can more readily diffuse in ferrite than in austenite.

Ferrite, therefore, both directly and indirectly promotes the equalization of chromium at moderate temperature after chromium carbide is precipitated. This diffusion goes on for a long time. If other ferrite-forming elements such as molybdenum and silicon are added, then immunity is acquired in substantially shorter time.

Investigation of two-phase stainless steels has led to a modification of the structural diagram established by MAURER, as shown in the diagram. If the metallurgist starts with a steel containing 18% Cr and 8% Ni, and increases the chromium and nickel in that proportion, a field of steadily increasing ferrite or delta iron is reached. The influence of the delta constituent on the capacity for immunization first becomes noticeable at about 10% ferrite. For practical purposes the ferrite phase cannot be increased beyond about 30% since the mechanical properties of the steel would be damaged too much.

H. HOUGARDY

Grain Boundary Attack After Annealing at 1100° F.

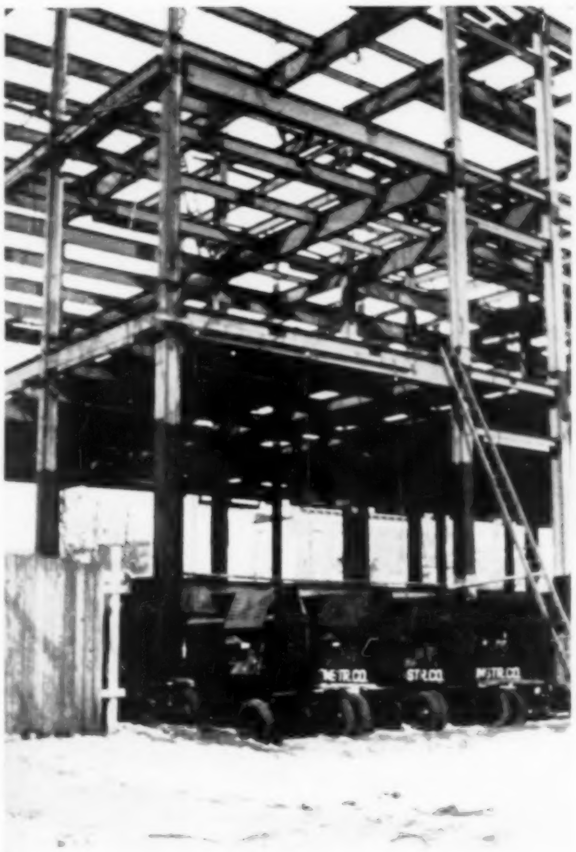
ANNEALING TIME	18% CHROMIUM, 8% NICKEL STEELS			22-10 STEEL 0.10% CARBON 15% DELTA PHASE
	0.12% C	0.05% C	0.10% C (stabilized★)	
Quenched (not annealed)	none	none	none	none
10 min.	pronounced	none	none	slight
1 hr.	very pronounced	slight	none	pronounced
5 hr.	very pronounced	pronounced	none	slight
7 hr.	very pronounced	pronounced	none	none
20 hr.	very pronounced	very pronounced	none	none
50 hr.	very pronounced	very pronounced	none	none

★With tantalum, titanium, or niobium.

Welding Generators Grouped During Erection

Letter from W. A. GARDNER
Lehigh Construction Co.

ALLENTOWN, PA. — An interesting addition to the growing list of arc welded buildings in metropolitan New York is Public School No. 213, on Hegeman Ave., Brooklyn. It is also a noteworthy application of efficiency methods of erection that more than compete with the old



Five Welding Machines Grouped for Care by Single Engineer During Rapid Erection of Steel Skeleton for School Building

fashioned riveting, to say nothing of the peace and quiet gained by the neighborhood.

This is a four-story building, 182 ft. long. The width is variable, since it has an east wing 90x60 ft., and a west wing 61x60 ft. The building was erected and welded within two weeks after placing the first column. Five 300-ampere Wilson welding generators, powered by Buda engines, were used by the contractors, Lehigh Construction Co., of Allentown.

Current control was facilitated by installing all five of the welding machines at one corner of the building, where they remained until the welding was completed, with an engineer in charge. Welding operators were able to signal for any necessary adjustments, and the close grouping of the machines permitted one man to take care of all of them without loss of time. Approximately 420 tons of structural steel were used in the construction of this modern building frame.

W. A. Gardner

Variation of Case Depth With Time and Temperature

Letter from Donald E. Babcock
Industrial Fellow, Mellon Institute

PITTSBURGH — While with the Republic Steel Corp. my attention was drawn to the data of Schlumpf on the "Time-Temperature-Penetration" curves (1928 Transactions, page 465) for the carburization of S.A.E. 1020 steel in vertical gas retorts using natural gas containing 95 to 98% methane as the carburizing agent. At the request of H. W. McQuaid, the data taken from the carburization of triangular test pieces were reduced to empirical equations, and the entire family of these curves was then found to be reducible to the following single general equation of the following forms:

$$P = 0.015 \left(\frac{\Theta}{2110}\right)^{10} \left[1 + \frac{1}{7} (10 \log_e T + T) \right] \qquad (1)$$

$$= 0.00214 \left(\frac{\Theta}{2110}\right)^{10} (7 + 10 \log_e T + T) \qquad (1')$$

where P is the penetration of the carbon case in inches per hour, Θ the absolute temperature in Fahrenheit degrees and T is the time in hours.

The individual curves of Schlumpf, when they were reduced to the general form

$$P = a + b \log T + cT \qquad (2)$$

where a, b, and c are characteristic constants and the temperature fixed, gave the following values for the constants a, b, and c:

Temperature	a	b	c
1750° F.	0.02651	0.03822	0.00355
1700	0.02022	0.02680	0.00274
1650	0.01498	0.02188	0.00209
1600	0.01127	0.01714	0.00173
1550	0.00866	0.01453	0.00134
1500	0.00382	0.00729	0.00118

These constants are given to five decimals to fit closely the empirical data, and need not be used in such extended form.

The reduction of the above family of equations to a single expression giving these values

Value of Constants, Calculated From Equation (1)

Temperature, °F.		$\frac{\Theta}{2110}$	$\left(\frac{\Theta}{2110}\right)^{10}$	Constants (Calculated)		
Observed	Absolute			a	b	c
1800	2260	1.0711	1.986	0.0298	0.0426	0.00426
1750	2210	1.0474	1.748	0.0262	0.0375	0.00375
1700	2160	1.0236	1.264	0.0190	0.0271	0.00271
1650	2110	1.0000	1.000	0.0150	0.0214	0.00214
1600	2060	0.9763	0.7868	0.0118	0.0169	0.00169
1550	2010	0.9525	0.6154	0.0092	0.0132	0.00132
1500	1960	0.9289	0.4783	0.0072	0.0103	0.00103

as a function of temperature and time was given in equation (1). The table on page 591 gives the constants for equation (2) calculated with the simplified equation (1) for the entire family of curves. The values for the constants within the limits of SCHLUMPF's data are fairly satisfactory for calculating the expected conditions in carburizing (except for values less than one hour, due to the nature of the equation).

For convenience in calculation, the general form (1′) is applicable to a particular temperature. The following form may be used for each temperature if the proper constant is employed.

$$P = K\,(7 + 10 \log_{10} T + T) \qquad (2')$$

where the values of K are as follows:

θ	K	θ	K
1800° F.	0.00424	1600° F.	0.00168
1750	0.00374	1550	0.00132
1700	0.00271	1500	0.00102
1650	0.00214		

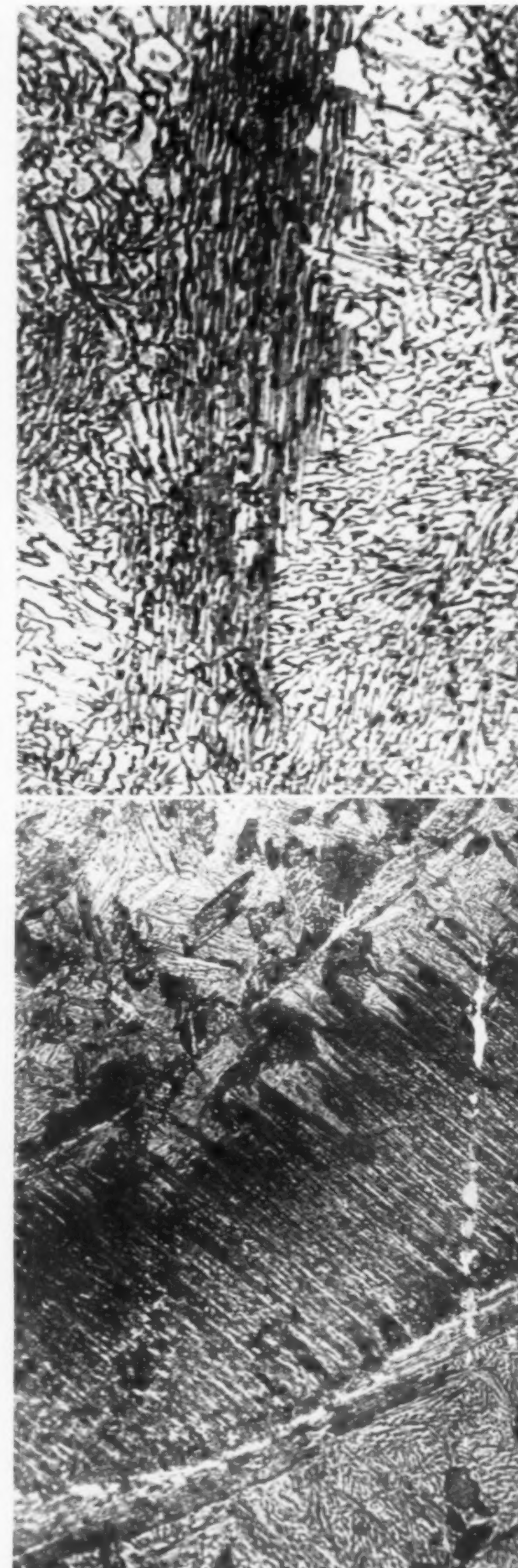
The values obtained in actual practice will be lower than these values if the steel is of higher carbon content, has any alloys that form carbides, or is highly alloyed with elements that do not form carbides. It will be lowered as the mass of metal being heated and carburized is increased, since the time required to raise this larger mass to carburizing temperatures may become a major factor. If, in such a case, the times *at temperature* are used, the calculated values should agree closely with observed data.

Another feature causing non-agreement is the difference between the temperature of the piece being carburized and the surrounding gases. Since the carburization reaction proceeds with the absorption of heat, the piece being carburized will be at a lower temperature than the surrounding carburizing gases.

Much more could be added to this discussion, but the object of this note was only to present to those interested in these data simple equations of considerable utility which rather accurately describe the facts observed in the carburizing temperature ranges.

Many will find an alignment chart more useful, and this has been prepared (page 587). A critical examination of the chart will show some slight deviations from the equations given, particularly with reference to the temperature Scale *A*. This change was made in the interest of accuracy over a slightly extended range. It is doubtful whether the values read from this chart for case depths of less than 0.003 in. and for times less than 0.5 hr. are very accurate because the curves were extrapolated.

DONALD E. BABCOCK



Unusual Structures in Steel, Found in 1910. At top: C 0.6%, Ni 7.0%, Brinell 220, magnified 1350 diameters. At bottom: C 0.8%, Ni 7.1%, Brinell 444, magnified 1000 diameters

Acicular Troostite

EDITOR'S NOTE: — PROFESSOR PORTEVIN has forwarded the following letter written to the lamented ALBERT SAUVEUR — a letter he could not have seen — with the following notation: "Doubtless he would have made this letter public, and you may therefore be interested in publishing it."

As can be seen it is about the nature of a microconstituent of steel PORTEVIN calls "acicular troostite" in his recent book "Introduction to the Study of Heat Treatment of Metallurgical Products". It is the same microstructure as the one defined "an acicular product, softer than martensite formed directly from austenite at temperatures between 900 and 300° F." by Messrs. VILELLA, GUELLICH and BAIN, in an article in METAL PROGRESS, August 1935, page 31.

Its nature is stated, provisionally, by ROBERT F. MEHL (METAL PROGRESS, October 1938, page 439) to be "an aggregate of ferrite and cementite nucleated by ferrite".

PROFESSOR PORTEVIN's letter follows:

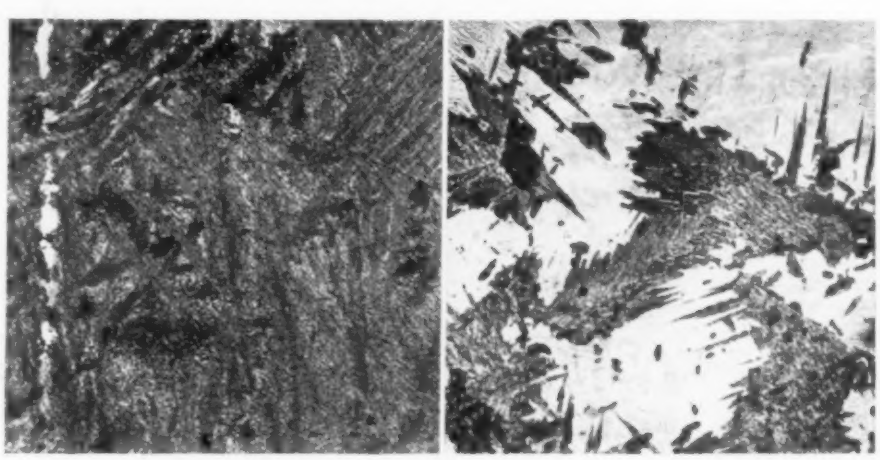
January 13, 1939

Prof. ALBERT SAUVEUR
20 Elmwood Ave.
Cambridge, Mass.

My dear friend:

You ask me, "What would OSMOND have said of the constituent designated as 'bainite' or 'acicular troostite'?"

I can answer that he would have said nothing for he would reserve his opinion. The reason I am so positive about this is that OSMOND really *saw* this new constituent and withheld any statement; he saw it because I showed it to him myself almost 30 years ago under the following circumstances:



Structure of Slowly Cooled, High Nickel Steels, Etched With Benedicks' Reagent, Magnified 200 diameters. Left: C 0.8%, Ni 7.1%, Brinell hardness 302. Right: C 0.65%, Ni 7.1%, Brinell hardness 477

In 1910 I performed some experiments on steels containing 7 to 12% nickel, annealing them at high temperature followed by very slow cooling, with the double intention of causing the self-hardening constituents to disappear and of reproducing the structure of meteorites. I thus obtained a complex constituent of elongated particles oriented according to the Widmanstätten structure, which I provisionally named "rod-like constituent" *(constituant en fuseaux)*. It would have been better to call it a "fascist structure" *(constituent en faisceaux)* after the fasces or bundle of rods surrounding the Roman ax handle, or a fascine or bale of sticks used by engineers for revetments.

Here are a few prints from the original negatives; since the negatives are 30 years old and somewhat yellowed, the prints are far from perfect. However, the use of very slow cooling permits one to observe the structures at relatively low magnifications.

OSMOND, examining these micrographs, withheld his opinion, suggesting that I continue the study and contenting himself with saying: "It must be a question of segregation of the iron-nickel solid solution". I therefore did not publish these photomicrographs at that time, naturally feeling in no position to give an explanation of the structure when OSMOND had nothing to say. Only incidental mention of these experiments was made by me in 1911 and 1921.

Actually, it seems to me that this constituent, obtained in these high nickel steels, is not without resemblance or without analogy to the constituent resulting from the intermediate Ar″ transformation, or the acicular structure in quenched plain carbon steels. It is therefore not new to me, but now its nature seems clearer. I would now say that it results from the separation of supersaturated ferrite in an unstable condition, causing the precipitation of cementite.

Studies of isothermal decomposition of austenite — notably by BAIN and his collaborators in your country — have brought this constituent in evidence much more clearly; such

studies have also brought to light other structural peculiarities.

It appears to me, therefore, as I said in my earlier reply to your questionnaire on the nomenclature of constituents pearlite, sorbite and troostite, that there is need to revise this nomenclature (but without revolutionary or destructive action) to make it more precise and more complete. I agree with your letter to the Editor of Metal Progress, in the July 1938 issue, that this can only be done by a meeting of an international commission, preparations for which must be made by preliminary studies of the problem in the various countries, enlisting the services of interested experts.

Thus, for France, I have requested Colonel Belaiew to prepare an exposition of the question which can be presented to one of the meetings of the French Association for Testing Methods. This will undoubtedly provoke a discussion, or at least an exchange of views, and in any event will arouse attention and bring us into contact with current American opinion on this controversy.

It is very much to be desired that the same thing could be done in various countries, for this could constitute a logical sequence to your questionnaire as well as a useful, not to say indispensable, study preliminary to the work to be undertaken by the proposed international commission.

This, then, is my present opinion, for which you asked.

I have so written my reply that you can make use of it and, if need be, can circulate it.

Very sincerely yours,

Albert Portevin

Preservation of Microspecimens

Letter from Edgar H. Howells
Development and Research Dept.
Bethlehem Steel Co.

Bethlehem, Pa. — It is frequently necessary to preserve the polished surface of a microspecimen for future examination. This is especially true if it exhibits unusual inclusions or a particular structure which might be lost on repolishing. We have found the following technique very satisfactory for this purpose:

A small piece of "Aroclor 4465", which is a resin obtained from the Monsanto Chemical Co. of St. Louis, is necessary. The Aroclor is placed on the polished surface and the metal heated until the resin is melted, when a microscope cover-glass is placed on top and pressed down until there is a thin uniform layer of it between the sample and glass. When cool, the excess Aroclor, forced from under the glass, can be removed with xylene, leaving the surface well protected by a tightly adhering thin glass. Care must be taken to prevent dust from being trapped under the glass.

The specimen, thus protected, is in good condition for safe keeping or photographing at a later date. There is no loss of detail in multiple phase inclusions or etched structures with distinct components.

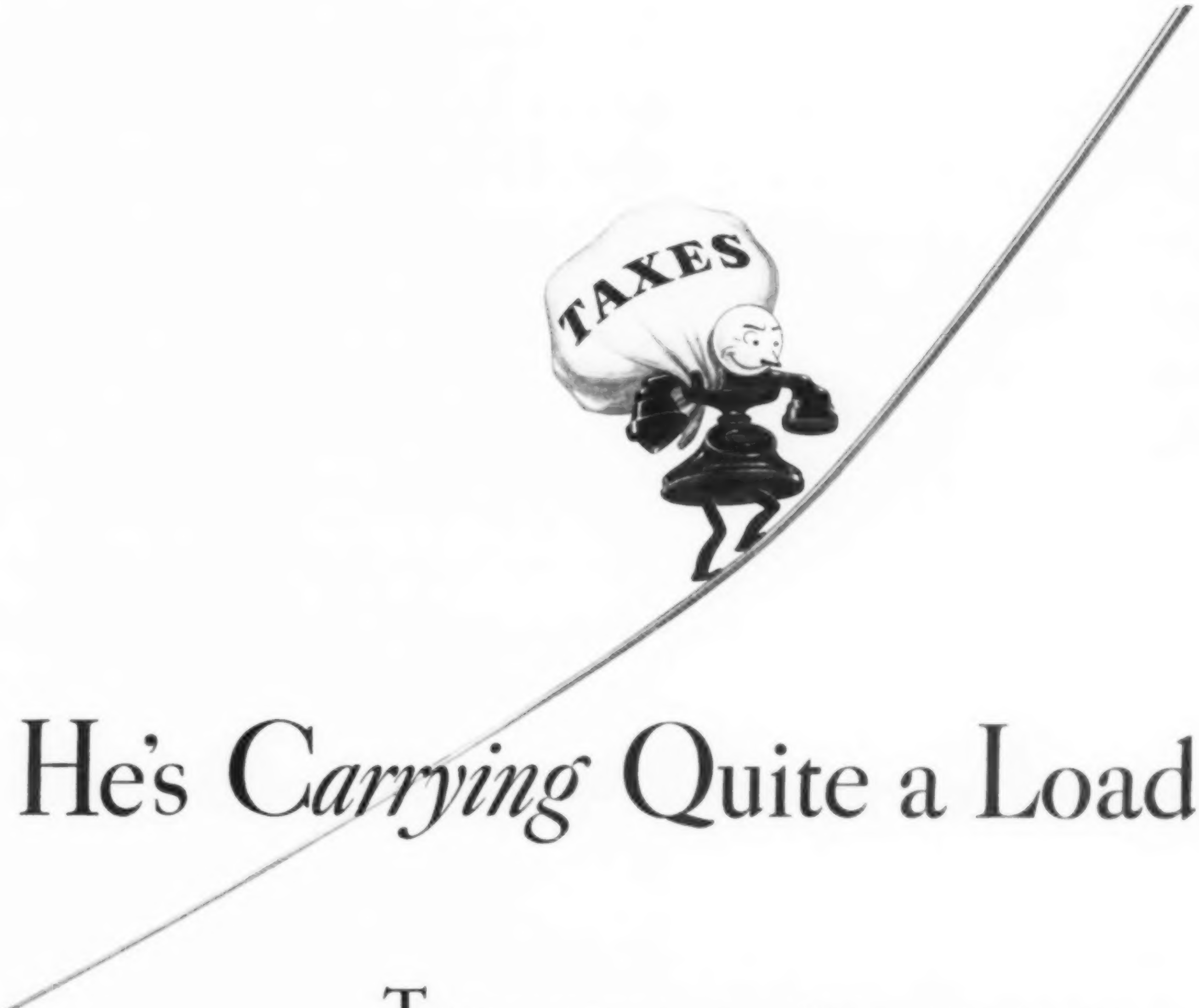
Edgar H. Howells

Ghosts

Houghton, *Mich.* — Much copper is being reclaimed from tailing sands, dredged from under water here in the Copper Country, and so it is not surprising to find remains of water creatures in copper from such a source. A little graveyard of this sort was recently discovered while peering through a microscope at a lead segregated area of copper-lead bearing metal.

Don H. Blackmar
Herbert F. Krohn
Graduate Students in Physical Metallurgy
Michigan College of Mining & Technology

Marine Remains in Bearing Metal Made of Copper Reclaimed From Submerged Tailing Sands


TAXES

Personals

E. J. Tompkins of Central Steel & Wire Co., Chicago, has been transferred to the Cincinnati office.

Conrad V. Coash has resigned as metallurgist of David Bradley Mfg. Works to accept a position as chemist with Sherwin-Williams Paint Co., Chicago.

Selected to present the 1940 Institute of Metals Lecture of the American Institute of Mining and Metallurgical Engineers: **E. H. Dix, Jr.**, chief metallurgist, Aluminum Research Laboratories, Aluminum Company of America, New Kensington, Pa.

F. H. Lawrence has been promoted from metallurgical engineer to assistant vice-president, Alan Wood Steel Co., Conshohocken, Pa.

J. W. Sands will have direction of the new field office of the Development and Research Division, International Nickel Co., recently opened in New York.

Promoted by E. F. Houghton & Co.: **C. R. Jackson**, from sales representative at Seattle to sales representative for the Pacific Northwest with headquarters in Portland, Ore.

Herbert G. Geittmann, Jr., formerly with Saginaw Malleable Iron Division, is now metallurgical engineer, Steel Sales Corp., Chicago.

Wilson Coats, formerly chief metallurgist of Reo Motor Car Co., is now assistant chief metallurgist of Nash Motors Division of Nash Kelvinator Corp., Kenosha, Wis.

Gilbert E. Doan, professor of metallurgy, Lehigh University, Bethlehem, Pa., has been made head of the department of metallurgical engineering to succeed **Bradley Stoughton**, National Treasurer, when he retires from active teaching this summer. **George L. Kehl** has been promoted from instructor to assistant professor of metallurgical engineering.

T. E. Barlow, formerly research engineer at Battelle Memorial Institute, has been appointed metallurgical engineer of the Cooper Iron and Steel Development Association, with headquarters in Cleveland.

J. E. Workman, formerly of Detroit, is now connected with the Chicago offices of the Latrobe Steel Co.

Now New England representative of the Ohio Crankshaft Co.: **Kenneth Stumpf**, formerly with Stanley P. Rockwell Co.

C. H. Kuthe, formerly sales engineer for Timken Roller Bearing Co. in Philadelphia, has been appointed technical advisor to the Michigan Division of Revere Copper and Brass, Inc.

Personals

G. A. Lux, chief chemist of the General Railway Signal Co. for the past 12 years, has been made technical director of the Lustre Chemical Corp. of Rochester, N. Y.

Walter B. Farnsworth is now chief metallurgist at the Monessen plant of Pittsburgh Steel Co.

E. J. Vanderman has resigned from Carnegie-Illinois Steel Corp. to accept a position as metallurgist for Hamilton Standard Propellors Division of United Aircraft Corp. at East Hartford, Conn.

Arthur W. F. Green has resigned as production engineer, Allegheny Ludlum Steel Corp., to become research metallurgist for Pratt & Whitney Aircraft Division of United Aircraft Corp.

Elected to membership in the National Academy of Sciences: **Zay Jeffries**, past president, consulting engineer, Incandescent Lamp Department, General Electric Co., Cleveland.

Nominated to receive the E. J. Fox Medal of the Institute of British Foundrymen: **H. A. Schwartz**, manager of research, National Malleable and Steel Castings Co.

Transferred: **Martin B. Gruzdis**, from Junior metallurgist at Watertown Arsenal to same position at Boston Navy Yard.

Franklin H. Pennell, secretary, Philadelphia Chapter, has left the Autocar Co. to become metallurgist in the sales division, Wyckoff Drawn Steel Co., Philadelphia.

Gordon Hess has been promoted to head the Houston territory for Republic Steel Corp.

T. N. Holden, secretary New York Chapter for 19 years, and **William Printz**, charter member, are now in business together as Holden-Printz Co., handling a general line of pyrometers and furnaces.

Fred A. Webber has been transferred from the Goddard Works, Worcester, Mass., to the Buffalo plant of Wickwire Spencer Steel Co., as metallurgist.

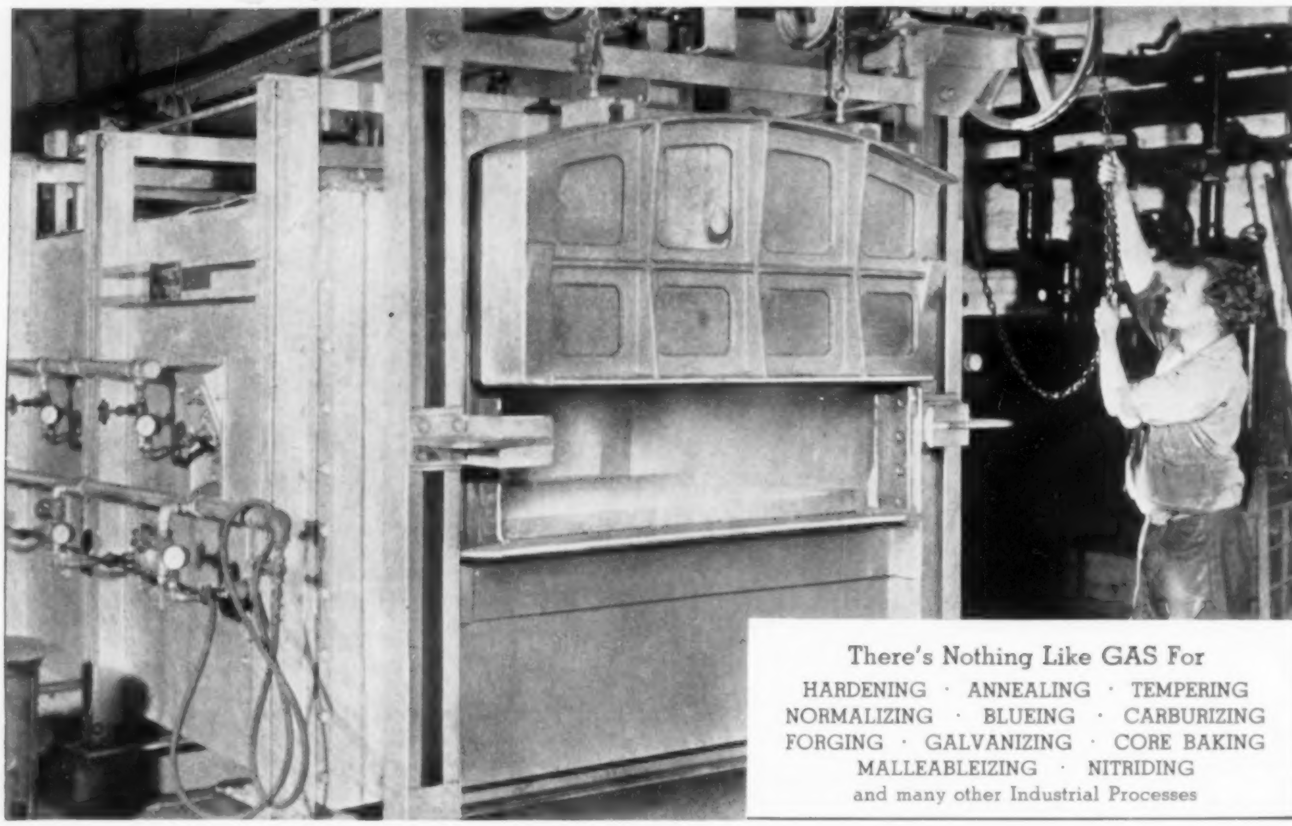
Leland E. Grant, chief chemist for the Chicago, Milwaukee, St. Paul and Pacific Railroad Co. for 11 years, has taken over the newly created position of metallurgical and welding engineer.

Elected director of the American Foundrymen's Association for 3 years: **W. B. Coleman**, past president, consulting engineer in Philadelphia.

Gordon J. LeBrasse has terminated his connection with Driver-Harris Co. to join the American Silver Producers' Research Project, National Bureau of Standards, Washington, D. C.

Gas ALSO TEMPERS THE COST OF TREATED METALS

Modern, GAS-fired furnace de luxe in use at New York City plant of R. Hoe & Company.



High in heat value, and capable of precise control, GAS produces perfect furnace conditions that result in a better product at materially reduced cost.

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THE TREND TODAY IS TO GAS FOR ALL INDUSTRIAL HEATING

Micro-Polish

(Cont. from page 562) the anisotropic properties are not hidden by any surface effect from polishing.

Reflection of light from a surface is accompanied by absorption of the incident beam, which in some cases is very large. Data on seven of the eight metals studied are in the table on page 562. If the incident beam is absorbed during reflection, some of it must have penetrated *into* the reflector. If the incident beam penetrates the reflector, there is still the possibility that an amorphous film may have been produced but is of insufficient thickness to cause total reflection in this layer. In other words, if there is a disorganized layer present, the incident beam may penetrate through this layer, may then be reflected from the organized zone beneath, and thus may produce anisotropic properties when using polarized light and crossed nicols. The possibility of such penetration is supported by the fact that gold foils have actually been hammered thin enough to transmit visible light.

Since the depth to which a beam of light can penetrate a substance is dependent on the angle of incidence of the light, a specimen of bismuth and tellurium was mounted on a universal stage so that the angle of incidence could be varied by any angle up to 50° to the perpendicular. It was found that anisotropic properties of the specimens could be detected at any angle permitted by the stage.

During this experiment with polarized light it was further noticed that certain of the metals gave stronger anisotropic properties than others under the microscope, varying inversely with the per cent reflectivity of the incident beam of light. In other words, the metals having the least percentage of reflection of the incident beam gave the strongest anisotropic properties. From this it might be inferred that anisotropism is a function of absorption by the atomic structure and that examination of opaque specimens by polarized light depends upon a limited penetration of the material.

In conclusion, I do not believe that one needs to be concerned about getting too good a surface polish and thus mask out the properties for polarized light, but rather one should strive for an excellent polish.

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Ernest E. Thum
Editor

William H. Eisenman
Business Manager

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